

ECONOMIC CROPS

VOLUME I

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BANANAS



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BANANAS

ECONOMIC CROPS

*A series of monographs on the chemistry, physiology,
and technology of food and food products*

Z. I. KERTESZ, Editor

VOLUME I

BANANAS: Harry W. von Loesecke



BANANAS

CHEMISTRY
PHYSIOLOGY
TECHNOLOGY

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INTRODUCTION TO THE SERIES

The printing of this book is the first step in the realization of a fond dream. For many years the editor has sought the production of a series of volumes dealing with the chemical composition and biochemical behavior of food crops in the broader sense.

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The widespread application of chemical analysis in plant research and in the increasing production of processed foods of plant origin has resulted in the accumulation of a wealth of analytical data on the chemical constituents present in plant tissues. Such data are now sought by workers in many branches of scientific research and technology, by chemists, physiologists, botanists, plant breeders, nutritionists, food manufacturers, and others. As this information became available, the great variability in the chemical composition of food crops became increasingly clear. Indeed, it is now known that the kind of soil used, cultural conditions, climate, seasonal influences, variety, the time and method of harvesting, conditions of storage and handling, and many other known and yet unknown factors cause variations which will often play an important part in the composition, behavior, and utility of food crops. These variations are often of such magnitude that the meaning and usefulness of average values is limited, and compilations of analytical results without any exact characterization of the plant tissues used are also of little value. Consequently, the need for critical and systematic discussions of the role of the factors causing variations in the chemical composition and biochemical behavior of economically important food crops became increasingly appreciated during the past few years.

Those interested in the composition and behavior of food crops might be arbitrarily grouped into two major categories. The first includes those interested in the production of crops: soil scientists, farmers, horticulturists, physiologists, ecologists, and many other groups might be placed in this first category, and plant pathologists and entomologists may also be listed with others interested in the production problems. The second classification includes those interested in the utilization of crops: the food processors and, ultimately, the nutritionists.

It has been a rather common experience to find a lack of understanding of the other's problems in both these groups. This is only natural, for those engaged in almost any of these activities must be specialists, often dealing with only a single phase of our elaborate food production schemes. Yet, time and again, the lack of an even superficial knowledge of the difficulties facing the food processor have limited the usefulness of those dealing with the various aspects of the crop production. Perhaps even more difficulty is caused by the reverse—the absence of sufficient appreciation by food processors of the problems in the large-scale production of uniform crops of high quality.

It is for such reasons that the present volume, as well as those to follow, are organized in a manner to aid both groups. While chemical composition and biochemical and physiological behavior are the central themes of these books, they also deal with botanical aspects and production factors, on one hand, and with the methods of utilization and processing, on the other. These discussions are not written for the specialist; the aim is to complement the picture for those in either group interested in chemical composition and the causes of variability.

Dealing with any topic in such a manner sets the authors to a most difficult task. It is impossible to find authors who are experts in all the various phases of agriculture, physiology, chemistry, and processing problems. The writing of these books has been entrusted to scientists and technologists who have had extensive experience with the crop in question and who, in addition to being specialists in certain aspects, will also appreciate the intricate relationship between crop production and processing technology. Needless to say, the assignment of writing a book on such

a broad scope requires much interest, restraint, and a spirit of co-operation from the author.

The editor wishes to thank the authors of this and further volumes now in preparation for their patience and skill in keeping the organization of their books within the framework of the series. Sincere thanks also go to the publishers, not only for affording a possibility for the organization and writing of this series, but for the many discussions of vital importance in developing this series from a nebulous idea into reality.

Any suggestions will be welcome concerning the organization, presentation, and any other matters that might lead to increased clarity and utility of these volumes. It is hoped that the effort which went into these books will be rewarded by the aid given to those dealing with food crops in attaining and maintaining high efficiency in the production of human food.

Z. I. KERTESZ

Geneva, New York
July 1, 1949

PREFACE

Several books dealing with the banana have been published during the past twenty-five years. An examination of these publications will show that they are primarily concerned with the methods of growing the fruit, the romance of the trade and the economics of production. Although the present volume briefly touches on a few of these topics, emphasis is placed on the biochemistry of the fruit and its products.

The volume is not intended as a handbook for those concerned with the raising of bananas. Rather it is for those engaged in fundamental researches, so that such workers may be cognizant of results already accomplished or in progress and better informed of the path ahead.

Free use has been made of the published results of those undertaking banana research, and every effort has been made to acknowledge appropriately the inclusion of such data.

Appreciation is expressed to members of the research staff of the United Fruit Company (especially to Messrs. George L. Poland, Alvah H. Slocum, and James T. Manion) for their helpful comments during preparation of the manuscript and for the use of various illustrations and the color plate. And thanks are extended to Dr. Z. I. Kertesz for his encouragement and aid during the course of the work.

Silver Spring, Maryland
June 1, 1949

HARRY W. VON LOESECKE

CONTENTS

Introduction to the Series	v
Preface	viii
I. History and Growth of the Trade	1
A. Origin of the Fruit	4
B. History of the Trade	7
C. Producing Countries	11
II. Structure and Development	17
A. Planting and Cultivation of the Tree ..	17
B. Effect of Mineral Constituents of the Soil on Those of the Fruit Pulp	20
C. Ontogenetic Development and Mor- phology of the Bunch	23
D. Morphology of the Fruit	29
III. Commercial Storage and Ripening Methods	39
A. Harvesting	39
B. Methods of Ripening	43
C. Use of Ethylene and Other Ripening Stimuli	47
D. Acetylene	53
E. Other Substances Affecting Ripening ..	53
F. Gas Storage	55
G. Effects of Chilling	59
IV. Chemical Changes during Ripening	67
A. Pulp-to-Peel Ratio	68
B. Respiration	71
C. Changes in Moisture Content during Ripening	76
D. Changes in Carbohydrates during Ripen- ing	78

2. Sigatoka Disease	154
3. Blood Sickness	155
4. Bunchy-Top Disease	156
B. Diseases of the Fruit	156
1 Cigar End Disease	156
2. Black Tip Disease	157
3. Botryodiplodia Fruit Rot	157
4. Banana Freckle	158
5. Pitting Disease	158
6. Black Finger-Tip Disease	159
7. Anthracnose	159
8. Thielaviopsis Fruit Rot	160
9. Lasiodiplodia Fruit Rot	160
10. Squirter Disease	161
11. Other Diseases	162
C. Insect Pests	163
1. Banana Weevil Borer	163
2. Beetle Borer	163
3. Lepidopterous Insect Causing "Ba- nana Scab"	163
4. Fruit Fly	164
5. Rust Thrips	164
IX. World Banana Production and Trade	167
Author Index	175
Subject Index	181

HISTORY AND GROWTH OF THE TRADE

The banana belongs to the genus *Musa*, comprising thirty-two or more distinct species and at least one hundred subspecies. The genus is divided into two broad sections: *Eumusa*, with edible fruits, and *Physocaulis*, with inedible fruits. For commercial purposes, *Eumusa* is divided into bananas and plantains.^{1,1a} Although much has been written concerning the family *Musaceae*, the most comprehensive treatise on the genera and species of the family is perhaps that by Baker.² A paper by Cheesman^{2a} is also of interest in this connection.

Among the more important technical writings on banana production might be mentioned that of Sanchez,³ who describes the varieties raised in Mexico; Ceferri,⁴ who discusses the varieties common to Italian Somaliland; McCaughey,⁵ on those varieties of the Hawaiian Islands; Hourwitz,⁶ who deals with banana cultivation in Palestine; Guadagnin,⁷ on the varieties of Brazil; and Garcia,⁸ on the bananas of Colombia. A more recent paper by Venkataramani⁹ gives results of a study of twenty-four varieties of Indian bananas. In this connection, it is interesting to

¹ P. Popenoe, *J. Heredity*, 5, 273 (1914).

^{1a} K. S. Dodds and N. W. Simmonds, *J. Genetics*, 48, 285 (1948).

² J. G. Baker, *Ann. Botany*, 7, 189 (1893); *Bull. Misc. Inform. Kew*, 1894, 229.

^{2a} E. E. Cheesman, *J. Genetics*, 48, 293 (1948).

³ C. G. Sanchez, *Cultivo del Plantano y Banano*. B. Torucco, Ed., Mexico, D. F., 1943.

⁴ R. Ceferri, *Il Banano*. Sansoni, Florence, 1943.

⁵ V. McCaughey, *Plant World*, 21, 1 (1918).

⁶ A. Hourwitz, *The Cultivation of Bananas in Palèstine*. Hassadeh, Tel-Aviv, 1930 (in Hebrew).

⁷ L. Guadagnin, *Ceres*, 6, 316 (1945).

⁸ E. Garcia, *El Planto en Colombia y particularmente en el valle de cauca*. Universidad Industrial dell Valle del Cauca, Colombia, 1945.

⁹ K. S. Venkataramani, *Proc. Indian Acad. Sci.*, B23, 113 (1946).

note that there are four hundred varieties of bananas in the Madras province of India alone.¹⁰

An examination of the publications cited will show that cultivated varieties of bananas are innumerable and in confusion, partly due to their tendency to bud variation, and partly because of the fact that the same variety is known by different names in various banana-producing regions. The following list of varieties, although by no means complete, has been compiled chiefly from data of Kervégant.¹¹ It is given here to indicate the complexities of any attempt to arrange the different varieties of fruit in an orderly manner.

Musa paradisiaca L.

Creole banana

yellow banana (Martinique)	white musk banana (French
true banana (Guadeloupe)	Guinea)
musk banana (Haiti)	white plantain (British Guiana)
	common plantain (Trinidad)

Saint Pierre banana*

giant banana (Martinique)	giant plantain (Granada, Ja-
fourteen foot banana (Mar-	maica)
tinique)	Pernambouc banana (French
	Guinea)

Black banana

black musk banana (French	black plantain (Trinidad)
Guinea)	

Plumed banana

M. corniculata Rumph.

Horn banana

horse plantain (British Guiana)	common plantain (Puerto Rico)
horn plantain (British Guiana)	Pisang† tandok (Malay states)
giant plantain (British Guiana)	Macho plantain (Mexico)
langa banana (French Guinea)	Harton plantain (Mexico)

Eyeless banana

horn banana of Puerto Rico
(Martinique) dwarf plan-
tain (Hawaii)

* This may be a sport of the Creole banana.

† *Pisang* is the Malay word for "banana."

¹⁰ *Report on the Marketing of Bananas*. India Central Marketing Dept., Delhi, 1945.

¹¹ D. Kervégant, *Le Bananier et son Exploitation*. Marit et Colon, Paris, 1935.

M. sapientum L.

Kakambou banana

collie banana (Martinique)
 post banana (Guadeloupe)
 Makabon banana (St. Lucie)
 Bluggoe banana (Grenada)
 Moko banana (Trinidad)
 Chamaluco banana (Puerto Rico)
 Mafafa banana (Puerto Rico)
 Piche banana (Puerto Rico)
 Malongo banana (Puerto Rico)

Cuatro filos (Puerto Rico)
 Largo filos (Mexico)
 Burro filos (Mexico)
 Barbaro filos (Mexico)
 Whitehall plantain (Jamaica)
 big bunch banana (Haiti)
 Burro banana (Cuba)
 apple plantain (Central America)

Seven weeks banana

sour banana (British Guiana)
 Indio banana (Central America)

vinegar banana (Puerto Rico)

Red fig banana

red creole fig, gold fig, bacove
 fig, Cuban banana (Martinique)
 violet fig (Guadeloupe)
 violet bacove (French Guinea)
 violet Guinea banana (Puerto Rico)
 violet-colored banana (Cuba)

violet banana (Mexico and the Philippines)
 red or claret banana (English speaking countries)
 giant red (Demerara)
 Pisang rajah udang (Malay States)
 Klui-nak (Siam)
 red banana (Italian Somaliland)

Apple fig banana

prune fig, pineapple fig (Guadeloupe)
 apple bacove (French Guinea)
 apple banana (English Antilles)

Manzana (Spanish Antilles and Central America)
 Massao or Maça (Brazil)
 Lady finger (Philippines)
 Go-sai-heong* (China)
 Klui-nam-wa (Siam)

Sugar fig banana

dessert fig, colibrifig (Martinique)
 coffee fig, bird fig (Guadeloupe)
 fique ti-malice (French Guinea)
 Pikien missifinger (Surinam)
 date, baby doll (niño), red
 Guinea banana (Central America and Puerto Rico)

cineto a la boca (Cuba)
 titiaro (Venezuela)
 gold, bananinba (Brazil)
 sugar banana (Australia)
 fig, Lady Finger (English Antilles)

* "Perfume that descends from the mountain."

Gros Michel

makanguia, Baudin fig (Martinique)

Raimbaud fig (Guadeloupe)

rose fig (Dominique)

butter bacove (French Guinea)

guaran or giant Guinea (Puerto Rico)

Johnson banana (Cuba)

Patriota Guinea banana (Colombia)

Roatan (Mexico)

Bluefields (Hawaii)

Pisang embu (Malay States)

Fiji banana (Fiji)

Gros Michel (United States, Great Britain, Central America, Trinidad)

M. nana Lour

little dwarf

big dwarf of the mountain

giuda (Italian Somaliland)

lacatan (Central America, United States, Great Britain)

ordinary big dwarf

The standard varieties of bananas handled in the trade belong to *M. sapientum* (Gros Michel) and *M. cavendishii* (Cavendish or Chinese banana). *M. paradisica* (plantain) is little known in the United States. The Lacatan has attracted serious attention as a possible substitute for the Gros Michel because of the Lacatan's resistance to Panama disease.¹² Cheesman and co-workers¹³ have pointed out that Lacatan, Bumulan, Giant Fig, and Masak Hijau are one and the same variety, best known as Lacatan.

A. Origin of the Fruit

Most authorities believe that the banana originated in the hot, tropical regions of southern Asia,^{14,15} but the seedless fruit as we know it today has been so long cultivated that it is probably impossible to be certain as to its place of origin.¹⁶ There is little doubt, however, that the banana was one of the first foods of man,

¹² C. W. Wardlaw and L. P. McGuire, *Great Brit. Empire Marketing Board Report*, 36 (1931).

¹³ E. E. Cheesman, C. W. Wardlaw, and G. L. Spenser, *Trop. Agr. Trinidad*, 10, 218 (1933).

¹⁴ H. J. Spinden, *Unifruitco*, 1, 653 (1926).

¹⁵ P. Popenoe, *J. Heredity*, 5, 273 (1914).

¹⁶ A. W. Hill, *Nature*, 117, 757 (1926).

and one of the first plants cultivated. Some botanists are of the opinion that the primitive banana, with fertile seeds, was cultivated by ancient man as a root crop, while the tender heart of the plant was also used as a food as it still is today in Ethiopia. Spinden¹⁴ does not accept this opinion, pointing out that the *Musa* genus does not excel as a root crop. What seems more likely to him is that banana plants with fruit of some food value were found growing wild and that these were brought under cultivation, the fruit being gradually improved by selection and cultivation. Beccari¹⁷ believed that the banana was an important cultivated crop in the Pliocene epoch. On the other hand, Paleontologists disagree as to whether man actually existed as a distinct species in that period.

Of interest is the recent theory of Rose¹⁸ who postulates that the edible banana arose by hybridization of wild diploid varieties of fruit containing twenty-two somatic chromosomes, and found growing in southeastern Asia. In this connection, Popenoe¹⁵ notes that cross pollination between two different species could easily take place, resulting in partial sterility of the hybrid. Such hybrids, asexually propagated either by man or by nature, would retain their sterility and a "horticultural variety" would thus be established. This postulation is given some weight by experiments described by Fawcett¹⁹ and by d'Angremond.²⁰ They were able to make the Gros Michel produce seeds by dusting the female flowers with pollen from *M. basjoo* and *M. arnata* Chittagong.

Other authorities explain the present-day seedless banana as a matter of simple selection, rather than on the basis of hybridization. Because all common edible bananas found in commerce today produce their fruit without fertilization, they are seedless.

How the banana was carried from the Indo-Malay region, where it probably originated, to America, appears uncertain. The fruit was probably transported far into the Pacific by the first

¹⁷ N. Beccari, *Foreste di Borneo*. Florence, Italy, 1902.

¹⁸ W. V. Rose, *Nyasaland Agr. Quart. J.*, 5, 90 (1945).

¹⁹ W. Fawcett, *The Banana*. 2nd ed., Duckworth, London, 1921.

²⁰ A. d'Angremond, *Ber. deut. botan. Ges.*, 30, 686 (1913).

migration of Polynesians about the time of Christ.²¹ Man, in his wanderings, probably also carried it eastward to India, the Mediterranean region, and finally to America. Writings by Valdes²² indicate that the fruit was introduced to the New World in 1516 at San Domingo. But some botanists hold that bananas were found in the New World long before Columbus. This belief is based on the fact that leaves resembling those of the banana tree have been found in pre-Columbia deposits in South America. There is always the chance, however, that the leaves found were not banana leaves, but those of some other plant closely resembling the banana plant.

Jessen²³ states that Alexander the Great found bananas growing in the Valley of the Indus river as early as 327 B.C. The fruit is represented on monuments of ancient Egypt and Assyria. White²⁴ reports that there is no direct record of the banana before the 5th century B.C. There is indirect evidence of its existence in the linguistics of southern Asia.

Ancient documents of China speak of the banana, but the time of introduction of the fruit into that country cannot be definitely established. The banana was probably unknown to the ancient Chinese because prior to the Christian era Chinese civilization was centered in the Yellow and Yangtze valleys where the climate is not suitable for the fruit.²⁵ Probably the first reference to the fruit in Chinese literature is found in the writings of Yang Fu, a native of Kwangtung, and an official at the end of the Later Han Dynasty flourishing about the 2nd century A.D.²⁵ Yang Fu described the banana plant, called *pa-chiao*, and he also gave the alternate name, *kan-chiao*.

The first clear references to the fruit are believed to be found in Greek, Roman, and Arabian writings where the authors refer to it as a remarkable fruit of India.²⁶ Pliny²⁷ called the tree "pala"

²¹ H. J. Spinden, *Unifruitco*, 1, 653 (1926).

²² G. F. de Oviedo y valdes, *Hist. gen. y Nat. de las Indias, Islas y Tierra-Firme del Mar Oceano*. Vol. I, Madrid, 1851, p. 290.

²³ L. S. Jessen, *Hawaii Farm and Home*, 8, No. 11, 4 (1945).

²⁴ P. R. White, *Z. Zellforsch. mikroskop. Anat.*, 7, 673 (1928).

²⁵ P. K. Reynolds and Mrs. C. Y. Fang, *Harvard J. Asiatic Studies*, 5, 165 (1940).

²⁶ H. J. Spinden, *Unifruitco*, 1, 653 (1926).

²⁷ Plinius, *Historia Naturalis*. Vol. XII, Sect. XII, Rome, 67 A. D.

and the fruit "ariena." However, his description causes some authorities to doubt whether or not he did describe the banana. Pliny does mention that the fruit was the food of the sages of India, and this gives us the *Musa sapientum* "the Musa of the wise men." Popenoe²⁸ states that "Musa" comes from the Sanscrit "moca" through the Arabic (*Mausor*, *Muz*) to the Latin form "musa." Some writers state that the genus was named after Musa, a physician of the Emperor Augustus. Popenoe discredits this story. Sixteenth century writers commonly referred to the fruit as "apples of paradise" or "Adam's fig," from the legend that the banana was the Tree of Knowledge of Good and Evil of the Garden of Eden. It was during this same century that the name "banana" came into general use. According to Popenoe,²⁸ it is the vernacular name given to the fruit by a tribe in the African Congo. Hartwell²⁹ says: "other fruits there are, termed Banana, which we verily think to be the Muses of Egypt and Suria." Reynolds,³⁰ referring to von Diedrich Westermann, also places the word "banana" as of African origin.

B. History of the Trade

The United States is the world's largest importer of bananas, and during World War II imported 80% of all bananas entering international commerce.³¹ In prewar years the fruit was the third most important agricultural food product imported into the United States from Latin America. It was exceeded only by sugar and coffee.

About forty years before the American banana industry got under way, the Gros Michel was introduced into Jamaica by Jean Francois Pouyat, a French botanist and chemist who settled in the island in 1820.³² Pouyat had a coffee plantation and, on his return from a visit to Martinique, he planted a Gros Michel on his

²⁸ P. Popenoe, *J. Heredity*, 5, 273 (1914).

²⁹ F. Pigafetta, *A report on the Kingdom of Congo and of the Surrounding Countries, from the writings of Duarte Lopez* (Rome, 1591); translated by M. Hutchinson, Murray, London, 1881, p. 68.

³⁰ P. K. Reynolds, *The Banana*. Houghton Mifflin, Boston, 1927.

³¹ H. Maness and R. G. Tucker, *World Banana Production and Trade*. U. S. Dept. Agr, Washington, D C., April, 1946.

³² *Dept. Sci. Agr. Jamaica Bull.*, No. 4, 1, 217 (1911).

estate. At first known as the "Martinique Banana-Pouyat," it gradually became known as the "Martinique Banana." The Agricultural Society functioning in the island at that time, on receipt of the first bunch of fruit from Pouyat, awarded him a doubloon for introducing so valuable a variety into the island. It is claimed that commercial plantings in Cuba and Central America were derived from Pouyat's Gros Michel, but adequate supporting evidence leaves some doubt as to the validity of this claim.

The story of the rise of the modern banana industry as related by Reynolds,³⁰ Adams,³³ and others³⁴ is one of a struggle against tropical diseases and the steaming jungle. The story begins in 1871 with the building of a railroad across Costa Rica by a New Yorker, Minor C. Keith, along with his uncle and brothers.³⁵ During a period of about two years, approximately 24 miles of the line were built at a cost of 4000 lives, including Keith's uncle and three brothers.

The Costa Rican government had neither money nor credit, and Keith had to have something to haul in order to make his railroad pay. He was aware that occasional cargoes of bananas were being imported into the United States by one Carl B. Franc on clipper ships from Aspinwall (now Colon) in Panama. There were no bananas in Costa Rica, but Keith obtained suckers and banana rootstock from Franc, and started plantations on the northern coast of Costa Rica. He soon went into partnership with Franc and extended his plantations to Nicaragua.

Keith's venture proved to be a monetary success. He continued building his railroad, cleaned up the new port of Limon, built a sea wall, installed one of the first sewerage systems in Central America, filled in swamps, and acquired a water plant.

Bananas were still a curiosity in the United States at this time, and at the Philadelphia Centennial in 1876 they sold for ten cents a piece. The eminence which the fruit was accorded even at

³³ F. U. Adams, *Conquest of the Tropics*. Doubleday, Page, Garden City, New York, 1914.

³⁴ *Background Information on Bananas*, Middle America Information Bureau, New York, 1945. Charles Morrow Wilson, *Empire in Green and Gold*. Henry Holt, New York, 1947.

³⁵ *Fortune*, 7, No. 3, 26 (1933).

the close of the 19th century is magnificently described by Mary Ellen Chase:³⁶

"Most remarkable of all her goods in those relatively fruitless days were crates of oranges, two kegs of white grapes, packed in sawdust, and—most wonderful to relate!—a huge bunch of bananas in a long, slatted frame. It may seem impossible today to wax romantic over a bunch of bananas! But in that huge frame standing on *The Golden Hunter's* deck, behind those masses of brown, tropical grass, were concealed far more than bananas, delectable and desirable as they were in themselves. Therein among those unripe, green protuberances, of whose snug members we caught now and then a baffling glimpse, lay a prestige and a preeminence among our fellows which in all the years that have passed I have never been able to recapture. My father had bought those bananas as a surprise. We were all excessively fond of them, but since they were tacitly recognized as an indulgence and since the price of them in the village store, at least of enough to supply our family, was prohibitive, we had never completely satisfied our desire."

Andrew Preston, a salesclerk of a Boston firm distributing banana cargoes, perceived the high prices being obtained for the fruit; he also noted that steamships of greater speed were replacing the slower sailing vessels. Preston, with Captain Alonzo Baker and Jesse H. Freeman, shipmasters, formed a central management for handling bananas in Boston. Shortly after this they obtained seven other business men and organized the Boston Fruit Company of which Preston became manager.

The company had an unfortunate beginning, for it lost all of its original capital of \$20,000 within two years. But the ten sponsors subscribed \$100,000 more, and by 1899 the Boston Fruit Company had formed six branches or affiliated companies.

Keith now appeared on the scene and formed a partnership with Preston which resulted in the formation of United Fruit Company in 1899. Keith's holdings in Central America and Colombia were merged with the interests of the Boston Fruit Company in the West Indies. At the time of the organization of the United Fruit Company, there were 22 other firms, corporations, or individuals engaged in importing bananas into the United States.

During the years that followed, the United Fruit Company

³⁶ Reprinted from *A Goodly Heritage* by Mary Ellen Chase with the permission of the publishers. Copyright, 1932, by Henry Holt and Company, Inc., New York, N. Y.

grew, and today it owns or leases approximately 3,500,000 acres of land in Cuba, Jamaica, Honduras, Guatemala, Nicaragua, Costa Rica, Panama, and Colombia. Of this acreage, about 125,000 are high-yielding and immensely valuable banana plantings. This tremendous expansion brought with it hundreds of schools for the workers and their families, jungle drainage, hospitals, wholesale vaccination, and medication of native citizens, advances in tropical medicine, and building of playgrounds, recreation centers, and clubs.

The phenomenal growth of this vast banana empire resulted not only in the sociological advances already mentioned, but also in charges by certain malcontents who saw evidence of exploitation.³⁷⁻⁴⁰ It is not the purpose of this book to discuss such charges.

Beside the United Fruit Company in the early days of the industry, the most successful was the Atlantic Fruit Company originally formed by Joseph DiGiorgio in Baltimore in 1901. It was first known as the DiGiorgio Importing and Steamship Company. In 1905 the Atlantic Fruit Company was incorporated under the laws of the State of Delaware; in 1911 the company was reorganized under the name of the Atlantic Fruit and Steamship Company. The firm grew and in 1913 the Atlantic Fruit Company was formed to take over the business of the Atlantic Fruit and Steamship Company.

In 1910, Sam Zemurray, a Bessarabian emigrant boy, formed the Cuyamel Fruit Company, operating in Honduras. Under the able direction of Zemurray, the company grew and became a serious competitor of United Fruit. Zemurray successfully experimented with irrigation with the result that the quality of Cuyamel's fruit was greatly improved and the yields increased. In 1930 United Fruit bought out Cuyamel, and a few years later Zemurray became president of the United Fruit Company. The reader desiring

³⁷ C. D. Kepner, Jr., *Social Aspects of the Banana Industry. Thesis*, Columbia Univ., 1936.

³⁸ L. Montes, *Bananas* (International Pamphlet No. 35). 799 Broadway, New York, 1933.

³⁹ C. D. Kepner, Jr., and J. H. Soothill, *The Banana Empire; A Case Study of Economic Imperialism*. Vanguard, New York, 1935.

⁴⁰ F. W. Bitter, *Die wirtschaftliche Eroberung Mittelamerikas durch den Bananen-Trust; Organisation und imperialistische Bedeutung der United Fruit Co.* Braunschweig, Hamburg, 1921.

details of Cuyamel's growth and its relation with United Fruit should consult *Fortune*.³⁵

Today, the most important competitor of United Fruit is probably the Standard Fruit and Steamship Company which was incorporated in 1926 to acquire the Standard Fruit and Steamship Company, Bragmans Bluff Lumber Company, and all preferred and 50% of the common stock of the Mexican American Fruit and Steamship Company. Early in 1935, the Haitian government signed a contract giving the Standard Fruit and Steamship Company the exclusive rights to purchase and export all bananas grown in Haiti. The company owns railroads, steamships, timber, coconut, and other properties in Central America and the United States. In 1942 Standard imported 3,097,262 stems of bananas, 60% of which came from Honduras and about 34% of which came from Haiti.

In England, the leading banana concern is Elders and Fyffes, Ltd. Early development of the banana trade in England was unfavorable because of the distances from the sources of supply. Around 1884 Fyffe, Hudson and Company, and Elder, Dempster and Company were importing the small Chinese banana from the Canary Islands. In 1901 the Imperial Direct Line between Bristol and Jamaica was started by Sir Alfred Jones who was Chairman of the Elder-Dempster Lines. The invention of cooling equipment by J. and E. Hall of Dartford made possible the shipment of bananas over long distances. As business expanded, a separate company was formed with Sir Alfred as chairman; this company was eventually combined with Elder, Dempster and Company to become Elders and Fyffes, Ltd. In 1910, United Fruit became owner of all the capital stock of Elders and Fyffes, Ltd.

C. Producing Countries

Bananas entering into international trade during 1934-38 averaged 106,992 million bunches (Table 49, Chapter IX).⁴¹ Even before World War II, production showed a slight decline due to disease. During the war, production was curtailed further, chiefly

⁴¹ H. Maness and R. G. Tucker, *World Banana Production and Trade*. U. S. Dept. Agr., Washington, D. C., April, 1946.

because of lack of shipping; and due to the shortage of material and personnel, banana diseases exacted their toll. Restoration of plantations to a high productive level will probably take from one to three years.⁴¹ In some countries it may require even longer than this because of disturbed social and economic conditions. It can be expected, therefore, that demand for the fruit will exceed the supply for several years to come.

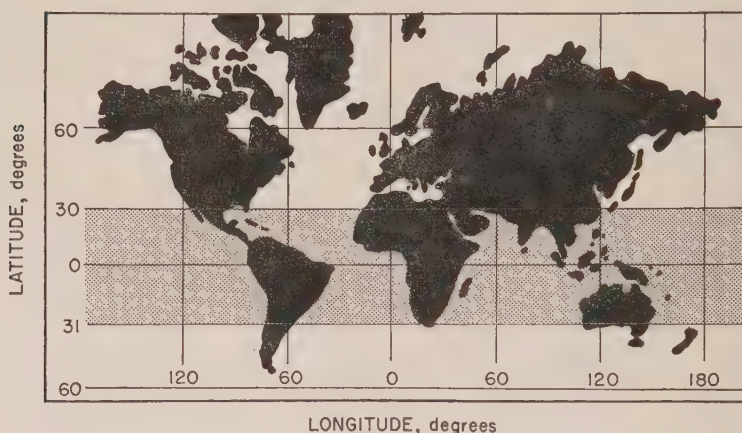


Fig. 1. Zone of banana production.

Bananas require a tropical climate where the temperature does not fall below 50°F. (10°C.) and seldom goes higher than 105°F. (40.5°C.), and where rainfall is frequent and scattered throughout the year. The fruit is, however, grown in regions where irrigation is sometimes necessary to compensate for the lack of adequate or properly distributed rainfall. The trees grow best in a fertile, well-drained soil, and protected from hot winds and hurricanes. The huge, undivided leaf of the banana plant offers considerable resistance to the wind.

Such ideal conditions as mentioned above cannot be found in the United States, and bananas are not commercially grown in this country. About 1921, the Florida Banana Growers' Association was organized at Tampa, Florida. This association attempted

to promote the growing of the fruit in Florida. The prospectus⁴² of the organization stated: "The growing of bananas is a commercial success in Florida. It is the easiest fruit to grow, the beautiful plants can yield heavy, money-making crops in the first year or in the early part of the second year, giving up to \$400 to \$1000 or more per acre per year." If bananas were ever grown in marketable quantities, the literature fails to record it. But today, bananas are grown as dooryard plants in Florida; the variety is chiefly *M. cavendishii*.

About three quarters of all bananas grown in the world are no doubt produced in the Western Hemisphere. Producing countries of importance are discussed below.

Mexico is one of the largest producers of bananas, the principal growing areas being Tabasco, Veracruz, and Chiapas. Over half the fruit produced in Mexico is consumed within the country.

Guatemala. Here production is on both the Pacific and Atlantic coastal plains, the larger acreage being on the Pacific coast. In the highlands, coffee planters use banana trees for shade for coffee plants; small amounts of inferior fruit are handled by minor operators. New land is now being built up from silt by diverting flood waters which creates good banana land free from Panama disease (Chapter VIII). The area of land on which bananas can be grown has also been increased by the use of overhead irrigation, thus making available land too rolling for surface irrigation.

Nicaragua. Bananas have been an important export crop in this country for more than forty years, but there is now a decline because of soil exhaustion and disease.

Costa Rica was one of the first Central American countries to produce bananas for export. New lands have been planted on the Pacific coast and some of the old lands on the Atlantic coast are being replanted, particularly by independent growers.

Panama (including the Canal Zone) is a large banana producer, most of the plantations being on the Pacific coast in the Province of Chiriqui.

Cuba. Bananas are produced in all parts of the country, but

⁴² W. E. Bolles, *Commercial Banana Growing* [in Florida]. Florida Banana Growers Association, undated.

fruit for export is raised almost entirely in Oriente Province in the extreme eastern part of the island. Beginning in 1936, production has declined mainly due to Sigatoka (Chapter VIII) and Panama diseases. For this reason, and also because the yield of fruit per acre is low and production costs high, it is doubtful that Cuba will be able to return to the level of her prewar exports of the fruit.

Dominican Republic. Bananas are grown chiefly for domestic consumption, and exports have never been large. However, new plantings have recently been undertaken on a large scale. These plantings promise to be of considerable commercial importance.

Haiti. Commercial banana production did not become important until 1933–1934. As previously mentioned, the Haitian government in 1935 gave the Standard Fruit and Steamship Company exclusive rights to purchase and export all bananas grown in that country. Labor costs are low, climatic conditions are good, and there are large areas suitable for commercial production. On the other hand, the fruit is small and producing areas are scattered.

Jamaica was the first commercial producer of bananas in the Western Hemisphere. Production from 1940 to 1944 has shown a decline because of the inroads of Sigatoka and Panama diseases. Labor costs have risen, and increased cost of fertilizer and Sigatoka control seem to discourage increased production to prewar levels. Extensive areas of banana land under control of large farmers have been ruined by neglect and disease.

Colombia. Commercial production is confined mainly to the Santa Marta zone. As in other coffee-producing countries, bananas are commonly grown as shade for young coffee trees. Bananas and plantains are produced throughout the warmer regions of the country for domestic consumption. Sigatoka greatly reduced banana production after 1941. Because of shortage of ships during the war years it did not pay to attempt to fight the disease, particularly since spray material was scarce.

Brazil. The banana industry has been developed primarily to supply the domestic demand. The fruit is produced in all Brazilian states, but commercial production is in São Paulo, Rio de Janeiro, and Minas Geraes, which account for 60% of the entire output. The São Paulo area produces about 25% of all bananas

grown in Brazil. Production has dropped considerably, domestic demand is high, and Brazil's exports of the fruit are not expected to be large in the immediate postwar years.

Ecuador. Production is in the hands of large estate owners and big companies; a common practice is to interplant bananas with cacao on the large estates. Ecuador is the largest producer of bananas on the west coast of South America and most of the export business goes to Chilean markets, the greatest demands being between June and December.

Canary Islands and Africa. The largest exporter of bananas outside the Western Hemisphere is the Canary Islands, where the trade was developed around 1900 by British and Norwegian steamship lines to supply the British market.

Bananas are grown throughout Equatorial Africa, the largest areas being the British Cameroons and French West Africa. Other important areas are the Ivory Coast, Mozambique, and Eritrea.

Asia. Formosa was a leading banana exporter during 1934–1938, where the trade was established about 1908 after the Japanese took possession of the island. Oceania, the Fiji Islands, and Western Samoa were also exporters in the Asiatic area.

STRUCTURE AND DEVELOPMENT

Bananas are propagated vegetatively by division of the main stem (rhizome), or by planting suckers which arise by the outgrowth of the buds on the rhizome.

A. Planting and Cultivation of the Tree

Planting and cultivation will vary somewhat in different banana-producing countries. The native fertility of the soil is utilized with the minimum amount of detailed treatment. In the past, when soil deterioration or the incidence of disease reduced the crop to a certain point, the plantation was abandoned and new land was opened up.⁴³ Today, however, this is not always true, and the use of fertilizers and sprays have to some extent nullified the practice of land abandonment.

As already mentioned, there are numerous species and varieties of bananas grown throughout banana-producing countries of the world. Some varieties, such as the Canary, will grow and yield some fruit under unfavorable soil conditions. The Gros Michel, on the other hand, is markedly affected by unfavorable cultural conditions and requires for its optimum growth soil with a high amount of natural or acquired fertility.⁴³

To grow satisfactorily, the plant should have at all times at least three feet of water-free soil in which to develop its root system.⁴⁴

In Central America, plantations are developed from virgin land, or, where circumstances permit, from silt deposits of rivers.

⁴³ C. W. Wardlaw, *Trop. Agr. (Trinidad)*, 6, 243 (1929).

⁴⁴ W. Popenoe, *ibid.*, 18, 8, 33 (1941).

Virgin land is cleared of undergrowth (underbrushing) and is then lined and staked out so that the plantation will have a semblance of orderliness when the trees come to maturity. The distance between plants will vary according to soil and climatic conditions.



Fig. 2. Roots of a banana plant showing "sword suckers."

Reynolds⁴⁵ states that in Central America the distance is generally 18 to 24 feet each way, and in Cuba and Jamaica, about 15 by 15 feet. Popenoe,⁴⁴ on the other hand, indicates a spacing of 11 by 11 feet in Jamaica, and 15 by 15 feet, and sometimes 16 by 16 feet or 18 by 18 feet, in Central America. In Brazil, the plants are set 10 by 10 feet or 10 by 11 feet, though occasionally plants may be set at 8 foot intervals in rows 12 feet apart.⁴⁶ In rich soils in Honduras and Guatemala, there are 550 plants to the acre; in

⁴⁵ P. K. Reynolds, *The Banana*. Houghton Mifflin, Boston, 1927.

⁴⁶ C. W. Wardlaw and L. P. McGuire, *Trop. Agr. (Trinidad)*, 10, 192 (1933).

heavy soils, from 600 to 650. In Colombia, from 550 to 575 plants to the acre is the general practice. Theoretically, the number of bunches per acre will correspond to the number of plants. Actually, the number harvested is less than this because of blow-downs and other damage.

Before the young plants appear above the ground, the large trees on the virgin land are felled. In some instances, especially where irrigation ditches are to be dug, the trees are felled immediately after underbrushing, and the area is burned, staked out, and planted. The felled trees and underbrush form a mulch, and under humid tropical conditions quickly decay and add humus to the soil. A large hardwood tree will require from two to three years for decay, but the smaller plants will rot in a few months.

About three months after planting, weeds and smaller branches of the felled trees are cut out to give the young banana plants a chance to grow. Cleaning in this manner is repeated at intervals of every three or four months. In Honduras and Colombia, disk harrowing is practiced to control the growth of grass.

As previously mentioned, native fertility of the soil is utilized to the fullest extent. According to Popenoe,⁴⁴ nitrogen is the only element needed as a fertilizer. This is supplied as sodium nitrate, ammonium sulfate, or calcium cyanamid. But as a rule, with the exception of Jamaica, extensive banana plantations receive no detailed cultivation. Baillon *et al.*⁴⁷ in their study of banana growing in the Canaries recommend fertilizers high in nitrogen and potash. Wood⁴⁸ also points out the need of manuring in Trinidad, and he used "synthetic pen manure" and potassium chloride.

In regions where rainfall is insufficient or widely scattered, the plants must be irrigated. On level tracts this is generally accomplished by irrigation ditches, but in hilly sections irrigation is by overhead pipe lines.⁴⁸ In the Canary Islands, water is obtained from winter rains in the higher regions and collected by "galleries" which consist of shafts driven into the hillsides. From the galleries the water is finally led to reservoirs where it is allowed to mix with rain water obtained during the rainy season in the lowlands.⁴⁹

⁴⁷ A. F. Baillon, E. Holmes, and A. H. Lewis, *Trop. Agr. (Trinidad)*, 10, 139 (1933).

⁴⁸ R. C. Wood, *ibid.*, 9, 352 (1932).

⁴⁹ C. W. Wardlaw, *ibid.*, 7, 320 (1930).

The reader desiring a detailed description of banana cultivation should consult Kervégant's comprehensive book.⁵⁰

B. Effect of Mineral Constituents of the Soil on Those of the Fruit Pulp

Unpublished data by the United Fruit Company throw some light on this subject.⁵¹ Results indicated that chlorides and sodium showed definite correlation between soil composition and the composition of the ash of the pulp of the fruit. Calcium and phosphorus showed very slight correlation. One explanation of the slight cor-

TABLE 1. PERCENTAGE OF MINERAL CONSTITUENTS IN DIFFERENT PARTS OF THE BANANA PLANT EXPRESSED ON A DRY BASIS

Mineral	Fruit		Stalk ^c	Leaves ^c	Pseudo-stem ^d
	Pulp ^a	Peel ^b			
Phosphates (P_2O_5)	0.179 -0.304	0.347-0.377	0.406	0.400	1.179
Potassium (K_2O)	1.21 -1.68	6.63 -7.73	6.548	2.759	2.154
Calcium (CaO)	0.028 -0.037	0.160-0.180	2.401	4.793	1.236
Magnesium (MgO)	0.18	0.304-0.315	0.660	0.770	0.391
Sodium (Na_2O)	0.201 -0.273	0.291-0.395	0.292	0.176	—
Iron (Fe_2O_3)	0.0064-0.0079	—	0.334	0.218	0.003
Sulfur (SO_3)	0.046 -0.053	0.472-0.657	0.275 ^e	0.333 ^e	0.552
Chlorides (Cl)	0.171 -0.308	1.724-2.122	0.062	0.111	1.214
Silica (SiO_2)	0.058 -0.096	0.558-0.790	1.257	4.076	0.697

^a F. C. Stratton and H. W. von Loescke, *A Chemical Study of Different Varieties of Bananas During Ripening*. United Fruit Co., Research Dept. Bull. No. 32 (1930).

^b R. Reich, *Z. Untersuch. Lebensm.*, 22, 208 (1911).

^c P. Huber, *Le Bananier*. Dunrod and Pinat, Paris, 1907.

^d Unpublished data, United Fruit Company. ^e As H_2SO_4 .

relation in the case of phosphorus may be based on the fact that, for certain plants, phosphate absorption is not directly proportional to phosphate concentration in the soil.

Correlation between soil composition and that of the ash of the plant is further complicated by the fact that the composition of the ash in various parts of the plant will differ (Table 1). Table 2

⁵⁰ D. Kervégant, *Le Bananier et son Exploitation*. Marit et Colon, Paris, 1935.

⁵¹ F. C. Stratton, United Fruit Company, Research Department, Boston.

gives the composition of principal parts of the banana plant. Referring to this table, it is difficult to understand the high value given for "crude fiber" in the fruit. The pulp of the fruit will average about 3.00% fiber (on a dry basis) and it is quite possible that Huber's figures include the peel as well as the pulp of the fruit.

There may be, particularly in extremes (*i.e.*, either a deficiency in some element or a marked overabundance of it), more or less localization of that element in a certain part or parts of the plant. Variations in soil composition may be reflected fairly uniformly throughout the whole plant in every part, or they may bear greater influence on some parts than on others. Thus, an element which shows little correlation between its concentration in the

TABLE 2. PERCENTAGE COMPOSITION OF PRINCIPAL PARTS OF THE BANANA PLANT EXPRESSED ON A DRY BASIS⁵⁵

Constituent	Stalk	Leaves	Fruit, just ripe
Nitrogenous matter	2.92	8.48	8.91
Glucose	—	—	11.81
Sucrose	4.55	2.78	4.50
Starch and related material	31.15	16.21	43.27
Fatty material	1.91	4.73	1.54
Crude fiber	23.81	26.82	22.82
Ash (CO ₂ deducted)	12.27	13.98	3.78
Extractives (by diff.)	23.39	27.00	3.37

soil and in one part of the fruit may show a better correlation in some other part of the plant.

Baillon *et al.*⁴⁷ point out that "plant nutrients may exert their effect on growth in various indirect ways in addition to those directly associated with the amounts in which they are taken up by the banana plant." In their study of the nutrient uptake by the banana plant (in the Canaries) they found that the plant absorbed a moderate amount of nitrogen, relatively little phosphate, and very large amounts of potash. In this connection, Kervégant⁵⁰ states that "the banana is an exhausting plant," by which may be meant that it rapidly depletes the soil of its nutrients. However, this is not true in the same sense that such crops as corn or sorghum, for instance, deplete the soil. Practical experience has demonstrated that bananas have been raised on the same soil for

forty years without a significant decrease in yields, and with felled plants acting as fertilizer.

Several references may be found in the literature concerning the composition of the banana tree itself. Thus, May⁵² reports that potash (K_2O) is present in the plant in unusually large amounts. Of particular interest in this connection is May's belief that there

TABLE 3. PERCENTAGE COMPOSITION OF A MATURE BANANA PLANT⁵³
EXPRESSED AS PERCENTAGE OF DRY MATERIAL

Part of plant	Nitrogen N	Phosphate P_2O_5	Potash K_2O	Magnesia MgO	Iron Fe_2O_3	Lime CaO
Main stem	1.07	0.28	8.24	0.99	1.57	2.09
Main root	1.04	0.22	4.12	0.69	1.61	0.63
Main small roots	0.90	0.12	2.10	0.69	1.94	0.99
Main leaf stems	1.03	0.28	4.20	0.91	0.65	3.99
Main leaves	2.24	0.38	2.93	0.72	0.24	2.22
Fruit	1.02	0.27	3.57	0.26	0.00	0.15
Fruit stem	1.28	0.86	14.28	0.75	0.86	0.61
Male flower	1.98	0.65	7.93	0.36	1.73	0.86
Sucker root	1.26	0.22	6.85	1.05	1.98	0.76
Sucker stem	1.84	0.45	8.95	0.67	0.70	0.73
Sucker leaf stem	1.60	0.41	7.51	0.75	0.28	0.91
Sucker leaves	1.65	0.53	4.72	0.98	0.48	1.04

is a striking relation between potash content of the plant and freedom from disease. High potash seems to indicate high disease resistance. Baillon *et al.*,⁵³ in their study on the nutrient uptake of the banana plant and its composition found the potash content in the head, stalk, and mature plant to be high. The phosphate content of the head and mature plant was low, while relatively high in the stalk. The fruit was noticeably low in percentages of lime, iron, and magnesia. Most of the lime was situated in the roots, stem, and leaves, and most of the magnesia and iron in the roots and stem.

In a very early paper by Fourcroy and Vauquelin⁵⁴ analyses are given of the juice of the plant. These workers found that the

⁵² D. W. May, *Porto Rico Agr. Expt. Sta., Rept. of the Director*, 7 (1927).

⁵³ A. F. Baillon, E. Holmes, and A. H. Lewis, *Trop. Agr. ATrinidadQ*, 10, 139 (1933).

⁵⁴ Fourcroy and Vauquelin, *Ann. Mus. Hist. Nat.*, 9, 301 (1807).

material consisted of potassium nitrate which made up the greater part of the salts present. Also found in considerable amounts was potassium oxalate, while potassium chloride was present in smaller quantities. The small amount of coloring matter reported by these workers was not identified. From what we know today, this is probably tannin.

The pseudostem contains about 92.4% water, the leaves approximately 82.6%, stalk 91.2% and the fruit about 79.9% water.⁵⁵ It is not stated at what period of growth the figures represent, but it is assumed that they are for a mature tree ready for the fruit to be harvested.

C. Ontogenetic Development and Morphology of the Bunch

As previously mentioned, the banana plant has no seed, but is propagated by young plants which bud from the underground tuberous stem or "bulb" of the older plant. In the beginning this bud gets all of its food supply from the parent bulb, but soon will



Fig. 2A. Cross section of banana pseudostem.

form leaves and roots of its own. This true stem or bulb (probably more properly called "tuberous rhizome") is the storehouse of food which may be used in the formation and growth of roots and leaves, but is chiefly used by the plant in the production of suckers

⁵⁵ P. Huber, *Le Bananier*. Dunrod et Pinat, Paris, 1907.

and in the development of the flowering shoot and of the fruit.⁵⁶ According to Teversham,⁵⁷ the reserve food supply of the sucker is largely starch used to supply the young suckers with food while they are still dependent on the plant sucker. The starch is changed to sugar in order that it may be utilized and assimilated by the growing buds.



Fig. 3. Development of the young bunch: (at left) flower bud emerging from ten-month-old plant—the leaves have been removed for a better view; (at right) flower bud a few days after emerging from the top of the pseudostem and before the bracts have fallen.

With growth, the underground suckers develop into plants consisting of an elongated trunk or pseudostem made up of closely packed overlapping layers. These layers are in reality leaf bases, the outermost layer being made up of the oldest leaf. Fawcett⁵⁶ states that the true stem, a tuberous rhizome, is the storehouse of food which may be used in the formation and growth of roots and

⁵⁶ W. Fawcett, *The Banana*. 2nd ed., Duckworth, London, 1921.

⁵⁷ T. F. Teversham, *J. Jamaica Agr. Soc.*, 8, 486 (1904).

leaves. Its chief use, however, appears to be in the production of suckers and in the development of the flowering shoot and the fruit. If the food supply of the tuberous rhizome is insufficient when the flowering shoot is forming, the bunch of fruit will bear only a few hands.



Fig. 3. Development of the young bunch: (at left) flower bud a few days after the bracts have fallen; (at right) young bunch with bracts off and the fingers starting to turn upward.

A single banana is called a "finger." The group of fingers known to the laity as a "bunch" is called a "hand," each containing from 14 to 20 individual "fingers." The cluster of "hands" attached to the stalk is called a "stem."

The young leaf, before it expands, is rolled around on itself inside of the plant trunk. Great pressure is required to force the emerging leaf upward through the false stem.⁵⁸ When one leaf

⁵⁸ A. F. Skutch, *Plant Physiol.*, 6, 73 (1931).

emerges another convolute leaf is formed within the stem. The last leaf to emerge is much smaller than the rest and serves to protect the flowers subsequently formed from direct sunlight. The leaves readily adapt themselves to different intensities of sunlight and shade, and when the rays of the sun are perpendicular, the sides of the leaf will collapse and hang together thus preventing too great evaporation. In wet weather, the upper surface of the leaves will become concave to catch the moisture. Leaf growth is surprisingly rapid, and Maxwell⁵⁹ found a mean daily growth of from 3.8 to 4.5 inches in banana plants growing in the Hawaiian Islands. He found a striking uniformity of growth and at the same time a gradual increase in the tree's capacity for assimilation, indicated by the gradual increase in the daily surface growth of leaf which amounted to from 59 to 66.9 square inches. This work was carried out over fifty years ago, and the methods used were crude in comparison with present-day technique. ✓

As leaf formation approaches completion, the inflorescence (flowering stalk) develops from the apical meristem which is used up in the process. At the time of formation of the flowering shoot, an embryonic bunch of fruit may be initiated. The number of hands on the embryonic bunch will depend upon the nutritional status of the rhizome. The flowers are in clusters or hands, each consisting of two rows, the hands being arranged spirally on the stalk. There are three types of flowers: ⁶⁰.

(1) *Female flowers* at the base of the stalk, with long ovaries which become the individual fingers of the bunch. Here the ovary is about two thirds the length of the whole flower.

(2) *Hermaphrodite flowers* high up on the stalk. The ovary is about one half the length of the flower. These form short, useless fingers on the bunch.

(3) *Male flowers* at the apex of the shoot where the ovary is about one third the length of the flower.

Each flower cluster is inclosed in a bract. When the flower is mature, the bract falls.

Since the female flowers eventually become the fingers of

⁵⁹ W. Maxwell, *Botan. Centr.*, 67, 1 (1896).

⁶⁰ C. W. Wardlaw, E. R. Leonard, and H. R. Barnell, *Ann. Botany*, 3, 845 (1939).

the bunch, their description would seem to be of importance.⁶⁰ The flowers consist of an elongated, inferior, trilocular ovary of three fused carpels, a five-lobed tubular perianth of three sepals and two petals, all united, and one small free petal, and a defective androecium. The perianth, androecium, and style become withered and discolored, but may remain attached for some time, more or less completely isolated from the ovary by a brownish corky layer. The ovules normally remain unfertilized, and at an early stage become brown in color and abortive. The reader desiring further data on floral morphology of the plant should consult the comprehensive study by White.⁶¹

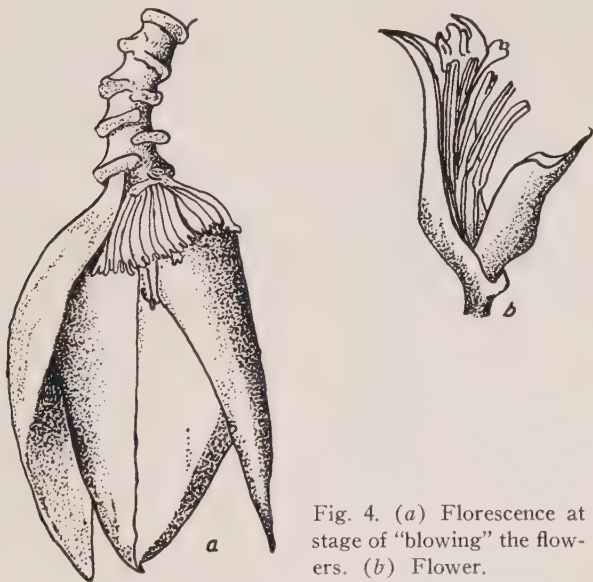


Fig. 4. (a) Florescence at stage of "blowing" the flowers. (b) Flower.

With continued growth of the tree, the stalk begins to elongate and the inflorescence bud is thrust upward under considerable pressure through the narrow central channel of the pseudostem. The bud finally emerges at the crown of the plant.

⁶¹ P. R. White, *Z. Zellforsch. mikroskop. Anat.*, 7, 673 (1928).

It is then said to be "shot." Continued elongation of the main stalk of the bunch causes the inflorescence bud to hang over, the bracts open and fall disclosing the female flower cluster or hands. The female flowers undergo further development without being pollinated or fertilized.

The time required from the first planting of the bulb to flower formation will vary. According to Fawcett⁶² "the actual length of time which is necessary from the first planting of the



Fig. 5. A bunch of bananas ready for harvesting. The terminal flower bud is shown developed below the bunch. This bud (see Fig. 4) is composed of maroon-colored bracts and clusters of creamy-white, yellow-tipped male flowers: (ab) neuter flowers; (m) male flowers; (l) portion of stalk from which male flowers have dropped.

bulb until the period arrives when the plant commences flower formation will vary according as the conditions for growth have been favorable or otherwise. But probably the time may be safely put down as somewhere between seven and nine months."

After the bracts have opened as described above, and the female flowers are disclosed, growth of the inflorescence stalk is rapid and the "hands" become separated by several inches of stalk.

⁶² W. Fawcett, *The Banana*. 2nd ed., Duckworth, London, 1921.

The bracts and the male flowers open and fall so that eventually a considerable length of stalk separates the male bud from the bunch proper. Further rapid growth causes the individual fingers of fruit to begin to fill out, and their increased weight bends the main stalk so that the bunch hangs in a vertical position (Fig. 5). If for any reason growth is curtailed, the bunch will remain in a semihorizontal position for a period, and an asymmetric bunch will develop. The reader particularly interested in illustrations of banana plantations is referred to the treatise by Mildbraed and Koch⁶³ which contains unusually fine reproductions.

It requires from two and one half to four months after "shooting" before the fruit becomes ready for harvesting; or a total of from 13 to 15 months after planting. The tree has then attained a height of about 30 feet and with a diameter at its base of about 16 inches. Only one bunch of fruit is produced to a tree.

A few weeks after bananas are planted a shoot appears. Behind it come other shoots, but these are cut away with the weeds so that all the soil food will go to the first plant. Six months after the parent plant has sprouted, a second one from the same root is allowed to grow. Then six months later a third, so that there are always three generations of plants growing at once. When the bunch has been harvested from the parent tree it is cut down, adding humus to the soil.

D. Morphology of the Fruit

Slocum⁶⁴ has made a rather detailed study of the morphology of the banana, particularly as it is affected by chilling (Chapter III). The description following is taken chiefly from Slocum's work.

The tissue of the peel may be divided into three main categories: (1) *the epidermis* (outer skin), (2) *parenchyma* (tissue underlying the epidermis), and (3) *the fibrovascular bundles* (Fig. 6).

The *epidermis* consists of a thin, transparent layer whose

⁶³ J. Mildbraed and F. O. Koch, "Die Banane, Ihre Kulture und Verarbeitung." *Reportorium specierum novarum regni vegetabilis*, 38 (1928).

⁶⁴ A. H. Slocum, *Effect of Low Temperature upon Cell Structure*. United Fruit Co., Research Dept. Bull. No. 48, 1933.

continuity is interrupted at regular intervals by stomata, minute valvular organs (Fig. 7). These stomata consist of pairs of specialized epidermal cells (known as "guard cells"), which are kidney-shaped, and between them is an elliptical opening communicating

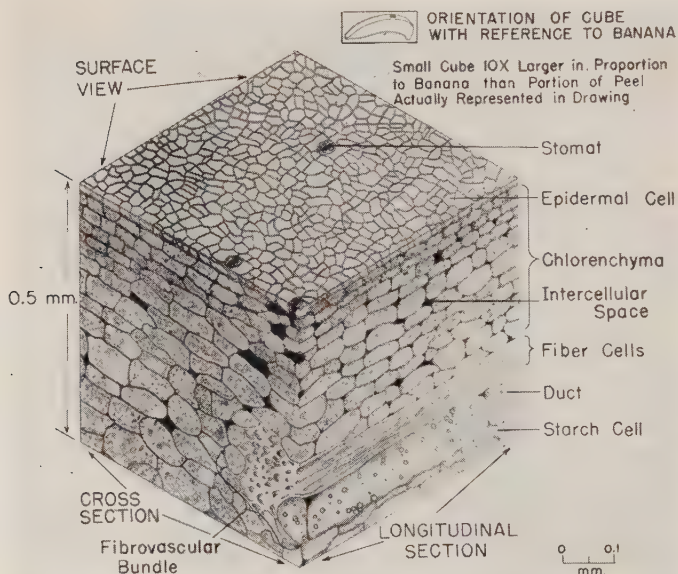


Fig. 6. A diagrammatic sketch showing structure of normal green banana peel.⁶⁴

with a cavity beneath. The cavity is continuous with the intercellular spaces of the chlorenchyma. Preliminary observations by Leonard⁶⁵ showed that the stomata of 3/4 full grade bananas from the time of harvesting to the "sprung"* condition remain closed irrespective of the environmental conditions. After the sprung stage, there is a tendency for some stomata to open. Leonard does not believe that a temporary opening of the stomata is responsible for increased rates of respiration and transpiration, but nevertheless they are not

* The stage at which the peel of the fruit starts to show a blush of yellow through the green.

⁶⁵ E. R. Leonard, *Ann. Botany*, 5, 115 (1941).

functionless but will open when sections of the epidermis are placed in water.

The epidermis serves as a protection against mechanical injury and the inroads of insects and fungi to the more delicate tissues that lay beneath. The epidermis is made up of small cells of irregular shape and roughly hexagonal in outline. All of these individual cells are joined closely together to form a tough, continuous membrane. They are slightly convex on their upper surface,

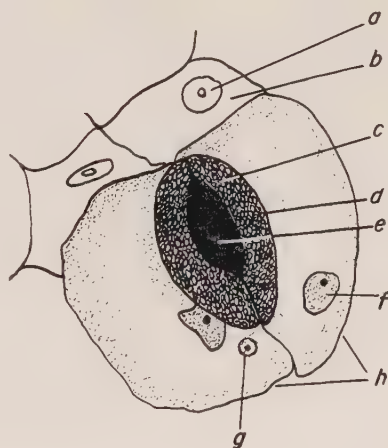


Fig. 7. Stoma of a green Gros Michel: (a) nucleus of epidermal cell; (b) epidermal cell near stoma; (c) chloroplasts containing starch grains; (d) guard cell of stoma; (e) stomatal cavity; (f) nucleus of auxiliary cell; (g) cytoplasm of auxiliary cell; (h) auxiliary cells surrounding stomatal cavity. Above them are seen two guard cells.

and where the edges of adjoining cells come together, slight grooves or depressions will be found. This imparts a distinctly striated appearance to the peel surface. The epidermis is overlayed with a thin film of protective cutin acting as a seal. As long as this film remains intact, the epidermis is impervious to water, and very little gaseous exchange can take place except by way of the stomata. Damage to the cutin will cause the underlying tissues to become discolored because of drying out and oxidation.

The *parenchyma* lies directly beneath the epidermis. It is uninterrupted except for the presence of occasional latex vessels. The *parenchyma* tissue makes up the main bulk of the peel, and

consists of relatively thin-walled cells, somewhat rectangular in outline and joined together in successive horizontal layers. The cells are significantly larger than those of the epidermis. The deeper beneath the epidermis the position of these cells, the greater their size. There is also a progressive alteration in the general outline of the cells as they progress to a greater depth beneath the epidermis. Near the epidermis they are roughly oblong in shape and distinctly flattened in a horizontal plane. Their vertical thickness is a little more than half of their lateral dimensions. Near the center portion of the peel, the cells become more and more rounded assuming an almost globular shape. This is apparently due to less crowding and a decrease in mechanical pressure. Intercellular spaces are considerably more extensive than in the tissues close to the epidermis. As the dividing line between the peel and pulp is approached, the individual cells are found to be loosely joined together in longitudinal strands of one or two cells in thickness with large spaces between them. Since they have very little mechanical strength, the peel and pulp can be easily separated. In separating the peel from the pulp, bits of parenchyma from the peel are usually left adhering to the surface of the pulp. An analysis of this material is given below:⁶⁶

Component	Percentage
Moisture	88.28
Reducing sugars (as invert)	5.44
Sucrose	1.05
Starch	0.84
Protein ($N \times 6.25$)	0.68
Pectin (as calcium pectate)	0.93
Protopectin (as calcium pectate)	0.21
Crude fat (ethyl ether extract)	0.53
Crude fiber	1.28
Ash	1.33

⁶⁶ Unpublished data of the author. The analysis is for a ripe Gros Michel, the peel flecked with brown. More nearly correct, the material may probably be described as fibrovascular elements making up a part of the inner surface of the middle mesocarp.

The internal structure of the parenchyma cells is of importance. A thin layer of protoplasm (protoplasmic utricle) lines the inner walls. Imbedded in the protoplasm are the plastids, which appear as oval bodies. In the outer portion of the peel the plastids contain pigments; and in the green banana, chlorophyll is contained in the first nine or ten rows of parenchyma cells. In the deeper layers of peel, each plastid becomes the center of starch accumulation. During ripening this starch is gradually changed to sugar. The nucleus is also present in the protoplasm, and the nucleus

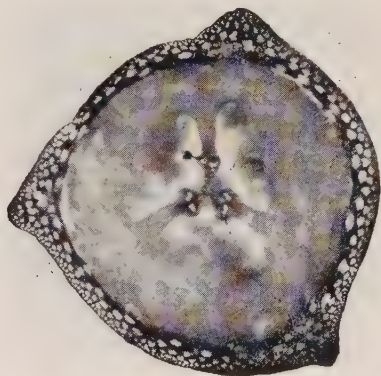


Fig. 7A. Cross section
of a green banana.

presides over changes of activities of the cell. The vacuole occupies the center of each cell, and contains a clear, watery fluid (cell sap) made up of sugars, tannins and other constituents necessary for the economy of the fruit.

The *fibrovascular system*, consisting of long, fibrovascular bundles scattered through the parenchyma at more or less irregular intervals, runs parallel to the long axis of the fruit. The bundles impart mechanical strength and rigidity to the peel tissues. At the same time they serve as pipe lines for the transportation of food and water. These bundles are relatively small and quite simple in structure near the surface of the peel, but in the deeper layers they become larger and somewhat more complex. The first bundles are found at a depth of nine or ten cells, or just below the lower limits of the chlorenchyma. The individual fiber cells are relatively long,

narrow, and thick-walled. They are quite uniform in diameter except at their extremities where they taper rather abruptly and overlap adjoining fibers. There appear to be no spaces between the cells and intercommunication is provided by means of numerous pits. Deeper lying bundles also have sieve tubes and tracheae, the latter serving primarily as water-conducting elements. They consist of long tubes with spirally thickened walls connecting directly or indirectly with tracheae in the main stalk. Usually, they occur in groups of two or three, but sometimes singly. The sieve tubes



Fig. 8. Latex from the peel of green bananas (greatly magnified). The refractive bodies in the globules are crystals of calcium oxalate.

consist of strings of elongated cells of moderate size with perforated end walls facilitating intercommunication. Their purpose is to serve as a means of transporting elaborated food material from the tissues in which they originate to other tissues where they are needed for growth or temporary storage. They are not indicated in Figure 6 because they occur only in the deeper tissues of the peel.

The *latex system* consists of the largest and most conspicuous cells in the banana. Thin-walled and barrel shaped, they are joined end to end in a single line sausagelike in fashion. In the peel, they will run parallel with the fibrovascular bundles, and are commonly contiguous with these. The latex cells will frequently occur in an entirely isolated position completely surrounded by ordinary parenchyma. Adjacent cells are thin-walled, flat-sided, and without starch grains or other visible contents.

Within the latex cells is a watery fluid carrying a very dense aggregation of spherical globules in suspension (Fig. 8). Early workers believed this material to be rubber. Prinsen Geerligs⁶⁷ mentions that banana skin contains rubber. Esch⁶⁸ claims to have obtained from green Martinique fruit a cloudy emulsion containing 10% rubber, or 50% of the dry weight of the expressed juice. The skins themselves were said to contain as much as 20% rubber. Griebel⁶⁹ also speaks of the milky juice as rubber. However, the material appears to be more closely related to chicle than to India

TABLE 4. ANALYSIS OF LATEX FROM THE PEEL OF GREEN BANANAS⁷⁰

Constituent	Variety A ^a	Variety B ^a
Water, %	83.34	78.07
Organic matter (gums, tannin, sugar, etc.), %	15.68	21.07
Total solids, %	16.66	21.93
Ash, % ^b	0.98	0.86
Sp. gr. (17.5°/17.5°)	1.042	1.040
Freezing point (uncorr.)	-1.0°C.	-1.0°C.

^a Commercial varieties.

^b Consisting chiefly of chlorides, phosphates, carbonates and sulfates of potassium, calcium and magnesium.

rubber.⁷⁰ In the author's work, a yield of latex corresponding to 2% of the weight of the green peel was obtained; and a yield of 10% crude gum, based on the weight of the latex was recovered.

The fresh latex is a white, milky fluid, but after standing in contact with the air for a short time, it will turn a light brown because of the tannins present. The latex is acid to litmus, and practically odorless but possesses a pronounced astringent taste. Tannins and furfural are present. Presence of carbohydrates is indicated by a positive α -naphthol test. No blue coloration is given with iodine. When treated with sodium hydroxide, a gel forms which will dissolve upon heating with the evolution of ammonia.

⁶⁷ H. C. Prinsen Geerligs, *Intern. Sugar J.*, 10, 372 (1908).

⁶⁸ W. Esch, *Gummi-Markt*, 4, 83 (1915).

⁶⁹ C. Griebel, *Z. Untersuch. Lebensm.*, 48, 221 (1924).

⁷⁰ H. W. von Loesecke, *Rubber Age*, Nov. 10, 1927, p. 129.

Glucosides are not present. An amyl alcohol extract of the latex gives a fatty residue with a phenolic odor after removal of the alcohol by evaporation. The addition of chloroform to the latex yields a gummy residue upon evaporation, which is soluble in water and gives an intense red color.

The gum was separated from the latex by centrifuging, washing, and drying. The material thus obtained was pure white immediately after washing, but upon drying became a brown, tacky, odor-

TABLE 5. ANALYSIS OF CHICLELIKE GUM FROM THE PEEL OF GREEN BANANAS⁷⁰

Component	Percentage
Moisture	11.46
Acetone soluble resins	44.45
Ether extract (hydrocarbons)	34.36
Albans	13.61
Fluavil	15.35
Protein (N $\times$ 6.25)	2.38
Ash	0.39

less, and tasteless mass; softening point about 40°F. (4.4°C.). Analysis of the gum is shown in Table 5. The gum could not be vulcanized with either sulfur or sulfur chloride.

Wolfson⁷¹ has carried out studies on the morphology of the pulp of the fruit. The cells of the pulp of the green fruit are long, boxlike in shape, thin-walled and contain numerous large starch grains in addition to the cytoplasm and nuclei (Fig. 9). There are few or no intercellular spaces and the cells adhere firmly to one another. In the tissues of the corresponding ripe banana, the starch grains have almost entirely disappeared; those remaining are small and irregular in shape because they are being converted into sugar (Fig. 10). A nucleus and cytoplasm are present in each cell indicating that the tissue is still living at this stage of development.

⁷¹ A. M. Wolfson, *Banana Morphology*. United Fruit Co., Research Dept. Bull. No. 4, 1928.

Tissues of the outer portion of the pulp show cells of a different shape, but in other respects they are similar to those of the



Fig. 9. Cells from center of the pulp of a green Gros Michel.⁷¹



Fig. 10. Cells from center of the pulp of a ripe Gros Michel.⁷¹



Fig. 11. Cells from the outer region of pulp of a green Gros Michel.⁷¹



Fig. 12. Cells from the outer region of the pulp of a ripe Gros Michel.⁷¹

axis. In green fruit (Fig. 11), the cells are held together by pectin bodies; they also contain numerous starch grains. These cells are

thin-walled and contain a nucleus and cytoplasm. Figure 12 shows corresponding cells in the ripe fruit.

Latex tubes are also present in the pulp, but here they run at right angles to the long axis of the fruit and outline the margin of the individual carpels.

**COMMERCIAL STORAGE AND
RIPENING METHODS**

In commercial practice bananas are never allowed to ripen on the tree. If so ripened, the peel splits rendering the fruit easy prey to insects and disease. Bailey⁷² has pointed out that the inner portions of the pulp of sound bananas are practically sterile. Regions of the inner coats of the peel may be sparsely inhabited by bacteria, which are held in check during normal ripening, but subsequently find conditions favorable for growth. Fungus and bacterial infection probably occurs while the fruit is still on the tree, through circulation in the plant juice.

Bananas are picked green and ripened under controlled temperature, humidity, and ventilation to prevent excessive accumulation of carbon dioxide.

A. Harvesting

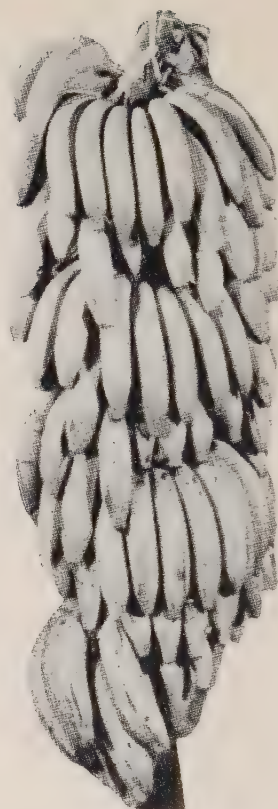
The fruit is cut while green but developed. At this time it is given descriptive terms such as "3/4 full," and "heavy 3/4 full" and "full" to indicate the grade and maturity at harvest. Not all banana-producing countries grade in a systematic manner. In some localities in India, for instance, the fruit is sorted according to the number of fingers in each bunch. In Madras the fruit is sorted into five classes, the standards for the first, second, third, fourth, and fifth classes being 200, 180, 160, 140, and 120 fingers, respectively.⁷³ The British system of grading is also slightly different from that of the American.

⁷² E. M. Bailey, *J. Am. Chem. Soc.*, 34, 1706 (1912).

⁷³ *Report on the Marketing of Bananas in India*. Marketing Series No. 49, India Central Marketing Dept., Delhi, 1945.



Three-quarters



Light full three-quarters

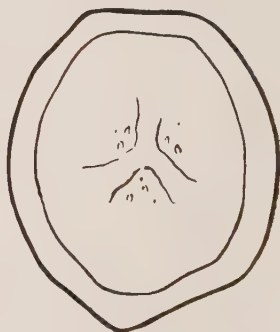


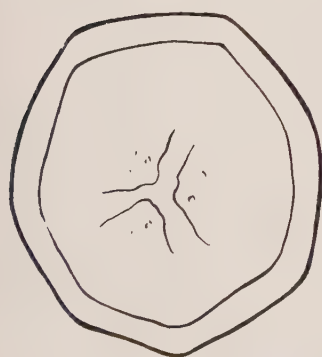
Fig.. 13. Various commercial grades of bananas.



Full three-quarters



Full



Cross sections of individual bananas below bunches are actual size.

Harvesting is subject to variation and is based on local experience. In general, bananas grown under conditions of continuous rainfall tend to yield large bunches of fruit; dry conditions tend to



Fig. 14. A "backer."

yield small fruit.⁷⁴ A bunch will weigh from 80 to 100 pounds, and contain from 6 to 14 hands (Table 6). The average number of hands in Central America falls between 10 and 11. Bunches having

TABLE 6. AVERAGE NUMBER OF INDIVIDUAL FRUITS OR "FINGERS" PER BUNCH FOR FRUIT GROWN IN HONDURAS^{74a}

Hands	Fingers	Hands	Fingers
6.....	77	11.....	190
7.....	99	12.....	213
8.....	122	13.....	235
9.....	145	14.....	258
10.....	167		

⁷⁴ C. W. Wardlaw, E. R. Leonard, and H. R. Barnell, *Ann. Botany*, 3, 845 (1939).

^{74a} W. Popenoe, *Trop. Agr. (Trinidad)*, 18, 8, 33 (1941).

less than 6 hands are not readily marketable under normal conditions.

In harvesting, the trunk of the tree is nicked a few feet below the bunch, causing it to bend at the place where it has been cut. The upper portion of the tree is then steadied to prevent it from falling and crushing the fruit. A "backer" catches the bunch on his shoulder, while the bunch is severed from the tree by the "cutter" using a machete. The tree is then cut down and quickly decays in the warm, humid environment.

In Jamaica, the method of cutting is different from that used in Central America, described above.⁷⁵ Each cutter in Jamaica is followed by numerous "headers." As soon as a bunch is cut, one of the headers carries it to a road or terminal; as many as 10 to 20 headers follow each cutter.

B. Methods of Ripening

Methods of ripening will vary somewhat according to the country. In India,⁷⁶ for instance, the fruit is not always picked while still green. With some varieties, the fruit is picked when the top hands have turned slightly yellow. Ripening is carried out in a primitive manner, the details of which vary in different parts of the country. In some locations (Madras, Punjab, Cochin, and Mysore), dried cakes of cow-dung, cinders, coke, charcoal, or cocoanut fiber are burned in earthen pots in godowns (a warehouse or storage shed; the name is a corruption of the Malay *godon*, meaning warehouse), where the bananas are stored so that the smoke from the fire may circulate around the bunches of fruit. In other parts of India (Bombay, Central Provinces, Hyderabad), bananas are smoked in heaps or in underground pits plastered with mud. They may also be ripened by storing them in paddy godowns, or by placing them on a platform above the earth and exposing them to the sun. Or they may be covered with green leaves obtained from certain plants. Where smoking is practiced, this is carried out for 36 to 72 hours during the summer season, and for 144 to 168 hours in winter. In Assam province, the fruit is exposed to sunlight for two to three hours prior to smoking.

⁷⁵ *The Story of the Banana*. United Fruit Company, Boston, 1941.

⁷⁶ *Report on the Marketing of Bananas in India*. Marketing Series No. 49, India Central Marketing Dept., Delhi, 1945.

In more progressive countries, the fruit is ripened in specially constructed ripening rooms (Fig. 15), which can be heated, ventilated, and the relative humidity carefully controlled. The original method of ripening bananas by electric heaters as a source of heat was said to have been invented in the United States by Leimann of Louisville, Kentucky.⁷⁷



Fig. 15. Banana ripening room.

Ripening rooms in England are not as highly developed as in the United States. In many instances in England the fruit dealer rents a cellar in a fruit market where he erects his ripening room.⁷⁸ Rooms of this type are not provided with controlled ventilation, but have skylights and roof panels as a makeshift. More modern rooms are provided with gas burners for heating, and water is usually sprinkled on the floor in the attempt to obtain the proper humidity. Fruit is ripened at 60° to 65°F. (15.6° to 18.3°C.) in summer, according to grade. In winter, West Indian fruit is ripened at 75°F. (23.9°C.), and so-called Naked Canaries at 70°F. (21.1°C.). These temperatures are maintained for 12

⁷⁷ Anon., *J. Agr. trop.*, 12, 64 (1912).

⁷⁸ Anon., *Food Manuf.*, 21, 428 (1946).

hours, and sometimes for 24 hours; they are then reduced to 60° to 62°F. (15.6° to 16.7°C.) according to the fruit and its condition. If the fruit does not "break color" within three days using this treatment, it is cut from the stem and ripened in boxes at 65° to 70°F. (18.3° to 21.1°C.). This is somewhat different from the technique used in the United States.

The most desirable temperature range for ripening the fruit in the United States lies between 62° and 68°F. (16.7° and 20°C.).⁷⁹ Strict adherence to this range depends upon the condition of the fruit and the rapidity with which it is desired to ripen. There are two factors of special importance determining the speed with which bananas will ripen under specified conditions. One of these factors is the maturity of the bunch at the time of cutting, as indicated by the fullness of the fingers or plumpness. This may be deceptive, however, because harvesting maturity is subject to variation and is based on local experience.⁸⁰ The other factor is the extent to which ripening has progressed during transportation from the tropics.

In the case of so-called "hard green fruit," temperatures of 73° to 78°F. (22.8° to 25.6°C.) for 12 hours are not harmful if high relative humidity is maintained. On the other hand, temperatures above 66°F. (18.9°C.) may be harmful to fruit that has started to turn yellow, or to ripe fruit.

Relative humidity is another important factor in ripening, and proper humidity is necessary to prevent excessive shrinkage, especially when the fruit is ripened at the higher temperatures. Relative humidity is generally maintained at 90 to 95% during the early stages of ripening. Ripe fruit is held at relative humidities of from 75 to 85% to avoid mold growth and injury to tender fruit.

During ripening, the fruit evolves carbon dioxide, ethylene, and probably small amounts of volatile esters. It has been found in practice that bananas will ripen more readily and uniformly if these gases are confined to the ripening room, provided the concentration of carbon dioxide is not too high. In general, ripening is retarded under the influence of carbon dioxide.⁸¹ High per-

⁷⁹ *Banana Ripening Manual*. Fruit Dispatch Co., Circ. No. 14, 1931.

⁸⁰ C. W. Wardlaw, E. R. Leonard, and H. R. Barnell, *Ann. Botany*, 3, 845 (1939).

⁸¹ F. Kidd and C. West, *Dept. Sci. Ind. Research (Brit.)*, *Rept. Food Invest. Board*, 1931, 100.

centages of the gas (around 30%) are toxic to an extent dependent on the concentration, duration of exposure, and condition of the fruit. Accumulation of carbon dioxide will also cause a reduction in the ascorbic acid content of the fruit.⁸²

Normal ripening will occur in 5% or higher concentrations of oxygen, but not in 2.5 and 0.1%. In 1% oxygen, ripening is not only delayed, but also abnormal in character.⁸¹ Perhaps, then, retardation of ripening in carbon dioxide is not due to the gas *per se*, but rather to the lack of oxygen (see Section F).

To accomplish *fast ripening*, the temperatures of the ripening room are so regulated that the pulp temperature of the fruit reaches 70°F. (21.1°C.), this temperature being attained at the rate of 2° to 3°F. per hour. After 24 hours, the temperature is reduced to 68°F. (20°C.) and is held at this temperature until the fruit is colored. The temperature is then further reduced to 66°F. (18.9°C.) and the fruit is held at this temperature. High relative humidity (90 to 95%) is maintained until the fruit is colored, and no ventilation is used until signs of coloring are visible.

In *medium-speed ripening*, the fruit is maintained at a temperature of 64°F. (17.8°C.) with a relative humidity of 90 to 95%. Ventilation practice is the same as in the case of fast ripening fruit.

Slow ripening is accomplished by warming the fruit to 60° to 62°F. (15.6° to 16.7°C.) and holding it at this temperature. Relative humidity is maintained at 90 to 95%. Ventilation (3 to 4 changes of air per hour) will aid in retarding ripening.

Ripe fruit is generally held at temperatures of 56° to 60°F. (13.3° to 15.6°C.) with a relative humidity of from 75 to 85%. Moderate ventilation (3 to 4 air changes per hour) is generally recommended.

Properly ripened fruit "should have a good attractive color and fresh appearance. It should have a firm pulp texture and good strength of peel in order to handle well during distribution to retailers. Flavor should not be impaired by the ripening treatment."⁸³

⁸² N. C. Thornton, *Contrib. Boyce Thompson Inst.*, 13, 201 (1943).

⁸³ *Banana Ripening Manual*. Fruit Dispatch Co., Circ. No. 14, 1931.

C. Use of Ethylene and Other Ripening Stimuli

The use of ethylene for hastening the ripening of fruit appears to have had its inception by Denny⁸⁴ and his work on the coloration of California lemons. Shortly after the publication of Denny's work, Harvey⁸⁵ announced that celery could be blanched by the use of ethylene, and in the same year Rosa⁸⁶ reported the acceleration of tomato ripening by the use of the gas. Rosa's work appears to have been the first in which ethylene was used for fruit ripening. In 1928 Harvey⁸⁷ described the ripening of bananas with ethylene and claimed to have discovered the method. He used one cubic foot of the gas to 1000 cubic feet of air and stated that one pound of ethylene would ripen at least 100,000 pounds of bananas. No data or chemical analyses were given.

In 1927 Chace and Church⁸⁸ reported that ethylene had no effect on citrus fruits, with the exception that coloring of the peel was hastened. Hibberd⁸⁹ experimented with bananas and gave one set of analytical results.

Wolfe⁹⁰ has critically analyzed Harvey's work and was unable to check his statement that fruit could be ripened to the yellow stage in from 42 to 48 hours at 95°F. (18°C.) by the use of ethylene. Wolfe points out that the fruit used by Harvey was far from normal, but the differences observed could not be attributed to ethylene. Wolfe believes that the question as to whether there is normally any stimulation of the ripening process by the use of ethylene is still moot. Certainly there is no stimulation in bananas that have already started to ripen at the time ethylene treatment is started. The gas will speed the ripening of so-called dormant fruit.

Presenting analytical data, Wolfe showed that bananas ripened with ethylene indicated a slightly greater increase in sugars and a decrease in starch from day to day than did the controls.

⁸⁴ F. E. Denny, *J. Agr. Research*, 27, 757 (1924).

⁸⁵ R. B. Harvey, *Minn. Hort.*, 53, 41 (1925).

⁸⁶ J. T. Rosa, *Proc. Am. Soc. Hort. Sci.*, 1925, 315 (1926).

⁸⁷ R. B. Harvey, *Minn. Agr. Expt. Sta. Bull.*, 247 (1928).

⁸⁸ E. M. Chace and C. G. Church, *Ind. Eng. Chem.*, 19, 1135 (1927).

⁸⁹ R. P. Hibberd, *Mich. Agr. Expt. Sta. Tech. Bull.*, No. 104 (1930).

⁹⁰ H. S. Wolfe, *Botan. Gaz.*, 92, 337 (1931).

Concentrations of ethylene from 1:100 to 1:1000 all seemed equally effective in bringing about the small differences observed. His data indicate that the respiratory activity of ethylene-treated fruit differs little or not at all from that of untreated fruit, when 12 hour periods are considered. This was true regardless of the concentration of the gas, and was due to the fact that the fruit had already reached the climacteric.

Harvey,⁹¹ on the other hand, reported an increase in respiration, but this increase was noted immediately after adding the gas. His results are not contrary to Wolfe's in this respect. Gane⁹¹

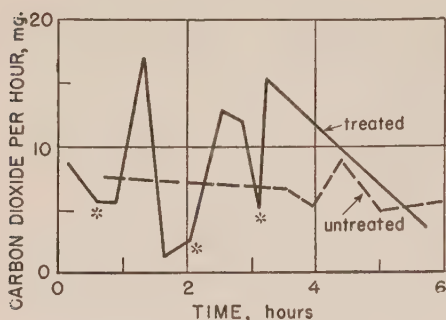


Fig. 16. Respiratory rate in bananas. Ethylene 1:1000 administered at points indicated by asterisks.⁹²

also found an increase in respiration in green fruit treated with ethylene, but little effect was observed in bananas already starting to ripen. Regeimbal, Vacha, and Harvey⁹² indicated that respiration was doubled or trebled within a few minutes after dosing with ethylene, and the rate fell off to a value lower than normal (Fig. 16). The authors explain that this may be due either to increased oxidation or to an increase in the permeability of the membranes permitting the diffusion of carbon dioxide already present in the cells. The rise after the second dose of ethylene seems to indicate an increase in oxidation rate rather than permeability change. Lynch⁹³ also noted an intensified respiration rate by ethylene in his studies.

⁹¹ R. Gane, *New Phytologist*, 36, 170 (1937).

⁹² L. O. Regeimbal, G. A. Vacha, and R. B. Harvey, *Plant Physiol.*, 2, 357 (1927).

⁹³ L. J. Lynch, *Proc. Roy. Soc. Queensland*, 47, 18 (1936).

Zavanju⁹⁴ found that bananas exposed to the action of ethylene had 13.82% total sugars on the 11th day, compared with 4.52% for the controls. Wolfe⁹⁵ has indicated that although ethylene treatment seemed to have no effect on respiratory activity, it did produce small but consistent increases in the rate of starch hydrolysis (Fig. 17). Unpublished data by the United Fruit Company show a more rapid hydrolysis of starch to sugars in ethylene-

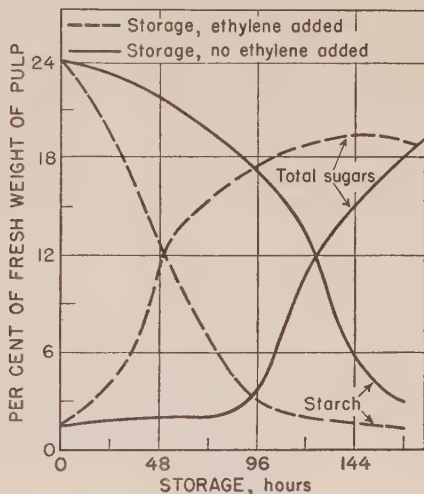


Fig. 17. Rate of ripening of bananas during storage at 72.6°F. with and without ethylene.⁹⁶

treated fruit than in untreated fruit. Hibberd⁹⁶ believes, however, that, even though ethylene accelerates the change of starch to sugars, the same results could be accomplished by additional heat and time.

Commercially, ethylene is used for producing uniformity in ripening and to accelerate slow ripening fruit. It has little effect upon fast ripening fruit. The gas is used in two or three successive applications at 12 to 24 hour intervals at the rate of one cubic foot of gas to every 1000 cubic feet of air. No harm will result from applications of greater concentrations, but no advantage is gained.⁹⁵

⁹⁴ A. Zavanju, *Rev. freddo.*, 23, 83 (1937).

⁹⁵ H. S. Wolfe, *Botan. Gaz.*, 92, 337 (1931).

⁹⁶ R. P. Hibberd, *Mich. Agr. Expt. Sta. Tech. Bull.*, No. 104, 3 (1930).

To understand the mechanism of the action of ethylene on bananas, it is first desirable to review briefly the data leading to the discovery that ethylene itself is a constituent of the cell of the fruit and is given off during respiration. These events have been related in some detail by Thornton.⁹⁷

Early in the history of the banana industry, it was noticed that the more mature fruit, even though green when loaded aboard ship, would ripen during the voyage from the tropics and affect the fruit in its immediate vicinity. This factor was later combated by the use of forced ventilation, and subsequently by refrigeration in conjunction with ventilation. Upon further investigation, it was found that the number of "ship ripers" varied directly with the carbon dioxide produced during respiration of the fruit. Since the nature of the substance producing "ship ripers" was unknown at this time, it was concluded that the percentage of carbon dioxide was an index to this unknown substance.

In 1923 Ridley⁹⁸ demonstrated that something produced by ripening bananas would accelerate the ripening of green fruit. This substance was not any of the then known by-products of the metabolism of the fruit. Ridley spoke of the unknown material as "X gas." Since Ridley published his results in an obscure journal, his data remained comparatively unnoticed by other workers.

As early as 1910 investigators in the Department of Agriculture of Jamaica⁹⁹ noticed that ". . . emanations from oranges stored in a chamber were found to have the effect of bringing about a premature ripening of bananas if these gases were passed through a chamber laden with this fruit." The nature of the gas was apparently unknown. It was not until 1940 that Biale¹⁰⁰ and Miller, Winston, and Fisher¹⁰¹ reported independently that ethylene is evolved by citrus fruits. Botjes¹⁰² and Huelin¹⁰³ had suggested earlier that the gas evolved by plant tissue was probably ethylene.

⁹⁷ N. C. Thornton, *Food. Industries*, 12, No. 7, 48 (1940).

⁹⁸ V. W. Ridley, *Fruit Dispatch*, 8, 523 (1923).

⁹⁹ Anon., *Ann. Rept. Jamaica Dept. Agr.*, 1910, 7.

¹⁰⁰ J. B. Biale, *Calif. Citograph*, 25, 186 (1940).

¹⁰¹ E. V. Miller, J. R. Winston, and D. F. Fisher, *J. Agr. Research*, 60, 269 (1940).

¹⁰² J. O. Botjes, *Tijdschr. Plantenziekten*, 39, 207 (1933); English summary, p. 211.

¹⁰³ F. E. Huelin, *Dept Sci. Ind. Research (Brit.)*, *Rept. Food Invest. Board*, 1932, 51.

In 1932 Elmer¹⁰⁴ reported that a gas emanating from apples inhibited the sprouting of potatoes, and in the same year, Kidd and West¹⁰⁵ brought about the early ripening of bananas by exposing them to the vapors of ripe apples. Gane¹⁰⁶ later demonstrated a definite increase in respiration of green bananas by subjecting them to air which had previously been passed over ripe bananas. He also confirmed the observations of Kidd and West that air passed over mature apples would hasten ripening of bananas.

In 1927 Gane¹⁰⁷ presented evidence to show that ripe bananas produced ethylene, and stated that the gas was a normal product of metabolism during the climacteric when it acts as an autocatalyst. Niederl and Brenner¹⁰⁸ obtained 0.1 to 0.2 cubic centimeters of ethylene per 100 pounds of fruit. They identified the gas by converting it to ethylene dibromide, converting this to acetylene by heating with alcoholic potash, and identifying by means of the silver halide.¹⁰⁹

Nelson¹¹⁰ believes that it is very probable that ethylene is consumed during the ripening process. The fact that ethylene treatment does accelerate the digestive process, although the fruit itself is producing ethylene, seems to lend weight to this probability. He further suggests that the use of ethylene is connected with the hydrolytic process in ripening. Nelson conceives of the gas as being produced by respiration and incidentally causing fluctuations in ethylene content of the tissues, while its essential function in ripening is concerned with hydrolysis. This effect is not a simple one. Nelson did not suggest a mechanism for stimulation of starch hydrolysis by ethylene, or its consumption in this hydrolysis.¹¹¹

Gane¹¹² is of the opinion that the reason why bananas which have just started to ripen are only slightly affected by ethylene is by

¹⁰⁴ O. H. Elmer, *Science*, 73, 193 (1932).

¹⁰⁵ F. Kidd and C. West, *Dept. Sci. Ind. Research (Brit.)*, *Rept. Food Invest. Board*, 1932, 55.

¹⁰⁶ R. Gane, *ibid.*, 1933, 126.

¹⁰⁷ R. Gane, *New Phytologist*, 36, 170 (1937).

¹⁰⁸ J. B. Niederl and M. W. Brenner, *Mikrochemie*, 24, 134 (1938).

¹⁰⁹ J. B. Niederl, M. W. Brenner, and J. N. Kelley, *Am. J. Botany*, 25, 357 (1938).

¹¹⁰ R. C. Nelson, *Food Research*, 4, 173 (1939).

¹¹¹ R. C. Nelson, *Plant Physiol.*, 14, 817 (1939).

¹¹² R. Gane, *Dept. Sci. Ind. Research (Brit.)*, *Rept. Food Invest. Board*, 1935, 123.

virtue of the fact that the fruit itself is producing the gas at this time. The addition of ethylene will increase the concentration of this gas inside the tissues and in this way may accelerate a process already started in all the cells; or it may raise the concentration above the threshold value in unchanged cells thereby causing these cells to ripen. The second alternative seems to be more feasible to Gane, because when ripening first starts it proceeds with the rapidity of a "trigger" action, and an increased concentration of ethylene above the threshold value is not likely to have any further effect. Gane conceives of ripening as starting first in a few cells of a fruit, and accompanied by the evolution of ethylene by these cells. The ethylene so formed diffuses into neighboring cells causing ripening to spread throughout the tissue. Herbert and Lynch¹¹³ have shown, for example, that ethylene diffuses readily through the epicarp and endocarp, but that the mesocarp offers some resistance.

Lynch¹¹⁴ points out that ethylene hastens the ripening of fruit, or of certain tissues of the fruit, only when they contain oxidizing enzymes. Pre-ripe bananas were found not to ripen in the absence of oxygen, despite the presence of ethylene in appropriate concentrations. Lynch postulates that since ethylene itself is generated in the fruit, it accelerates the ripening process by a direct stimulation of the oxidizing enzymes, the gas assuming the role of a coenzyme. Assuming this hypothesis to be correct, it should be possible to predict which fruits are amenable to ripening by ethylene. Fruits containing oxidases distributed uniformly through their tissues should respond to gas treatment. Such fruits as bananas, apples, and pineapples contain oxidases and do in fact respond to ethylene treatment. Action with pineapples may be unsatisfactory because of the difficulty of gas penetration and the size of the fruit. As previously pointed out, ethylene treatment of bananas is not effective if administered in the post-climacteric phase.

It has already been noted that the treatment of bananas with ethylene will accelerate hydrolysis of starch and increase respiration, provided that such fruit meets certain conditions previously discussed. The action of ethylene on the vitamin potency of the fruit is of nutritional significance. There are apparently no pub-

¹¹³ D. A. Herbert and L. J. Lynch, *Proc. Roy. Soc. Queensland*, 46, 72 (1935).

¹¹⁴ L. J. Lynch, *ibid.*, 47, 18 (1936).

lished data showing the effect of the gas on the thiamine, riboflavin, carotene and niacin contents of the fruit. Thornton^{115,116} has found that in the case of ascorbic acid, the presence of ethylene in concentrations of 1:8000 to 1:500 had no detrimental effect on the content of this vitamin in bananas.

D. Acetylene

In 1928 Hartshorn¹¹⁷ reported before the Physiological Section of the Botanical Society of America that bananas placed in a container with calcium carbide (or exposed to moist air that had been passed over calcium carbide) and then through respiratory chambers increased the rate of fruit ripening as indicated by change in color, pressure test, flavor, starch content, and respiratory rate. The effect was marked with chilled fruit. The quantity of carbide could be varied within wide limits with the same result. Unfortunately, Hartshorn gives no data relative to the concentration of acetylene. It was found that the maximum respiratory rate during ripening may not be greatly changed by the gas, except in the case of severely chilled fruit. The effect appeared to be chiefly in the abbreviation of the period of low activity normally occurring at the beginning of the ripening process, or which may be considerably extended by unfavorable conditions, such as chilling.

It has been found¹¹⁸ that most olefins and even carbon monoxide act in the same manner as acetylene.

E. Other Substances Affecting Ripening

Ramsey and Butler¹¹⁹ found that ammonia caused darkening of the peel of bananas, this darkening persisting even after the fruit had been removed from the influence of the gas. At a temperature of 70°F. (21.2°C.) and 85% relative humidity, a concentration of 4.2% ammonia caused, in one hour's exposure, a browning of 25% of the surface of the fruit peel; the ribs were dark brown to black and the ends, black with some reddish brown spots. After

¹¹⁵ N. C. Thornton, *Contrib. Boyce Thompson Inst.*, 13, 201 (1943).

¹¹⁶ N. C. Thornton, *ibid.*, 14, 295 (1946).

¹¹⁷ R. Hartshorn, *Am. J. Botany*, 15, 619 (1928).

¹¹⁸ *Unpublished data*, United Fruit Co., Research Dept.

¹¹⁹ G. B. Ramsey and L. F. Butler, *J. Agr. Research*, 37, 339 (1928).

12 minutes' exposure to this concentration a few small yellowish brown spots were apparent. At concentrations of 29.3%, there was uniform blackening of the peel in one hour.

Gane¹²⁰ reported that such substances as ozone, sulfur dioxide, hydrogen sulfide, iodine, hydrogen peroxide, Vaseline, sulfur, and amyl acetate produced blackening of the peel of bananas without ripening the pulp. An earlier paper by Gane¹²¹ indicated that concentrations of ozone amounting to 25 to 40 p.p.m. affected respiration, and ripening was delayed. If the fruit was within a few days of its period of rapid ripening, exposure to ozone was not effective in retarding the ripening process.

A British patent¹²² describes an apparatus for treating bananas (among other fruits and nuts) with ultraviolet rays to facilitate ripening, or to destroy microorganisms. Unpublished preliminary experiments carried out by the Research Department of the United Fruit Company indicated that ultraviolet light (using a quartz mercury vapor lamp without screens) had a burning effect upon the fruit, producing a marked browning of the peel. This effect was not due to the temperature immediately surrounding the fruit during exposure, nor was it due to low humidity. In some cases, ultraviolet light retarded ripening. This was found to be true even though exposure was not sufficient to produce browning of the peel. In instances in which the latex had oozed from the green fruit, a protective action was noted, for those parts of the peel covered by the latex had a normal color. In the older types of mercury vapor lamps considerable ozone was created, and it may be that the browning effect was due to ozone. However, more recent work with present-day commercial lamps of the type installed in meat cases, caused browning of the fruit, when such lamps were installed in ripening rooms. This browning was apparent even when the rays were reflected from the aluminum painted ceilings, and no direct rays reached the fruit.

Bottini¹²³ reported that air containing amyl esters of valeric acid accelerated ripening of bananas. Air containing ethyl or amyl

¹²⁰ R. Gane, *Dept. Sci. Ind. Research (Brit.)*, *Rept. Food Invest. Board*, 1935, 123.

¹²¹ R. Gane, *Dept. Sci. Ind. Research (Brit.)*, *Rept. Food Invest. Board*, 1934, 128.

¹²² D. McKinlay, *Brit. Pat.* 272,775, December 8, 1926.

¹²³ E. Bottini, *Ann. sper. agrar. Rome*, 15, 31 (1934).

acetate caused stains or general yellowing of the peel; acetic acid and acetaldehyde initiated yellow spots, while ethyl alcohol encouraged mold growth.

A recent paper by Mitchell and Marth¹²⁴ indicates that starch hydrolysis (judged by iodine and taste tests) in bananas sprayed with 2,4-D (*i.e.*, 2,4-dichlorophenoacetic acid) in concentrations of 100 to 1600 p.p.m. was accelerated as compared with the controls. The acceleration noted apparently depended upon the variety of fruit and its past treatment. The investigators used the pure acid and no odor was apparent in the ripened fruit.¹²⁵ The researches were more or less limited, and it would seem desirable to carry out further work and obtain data of a more quantitative nature.

F. Gas Storage

It has been previously mentioned that certain gases, particularly carbon dioxide, retard normal ripening. Ozone also has a retarding effect and causes the stomata to close.¹²⁶ Thornton¹²⁷ has shown that the oxygen uptake by bananas is reduced by carbon dioxide, but that the reduction is not marked until 30% or more of the gas is employed.

Thornton¹²⁸ stored banana tissue in 72% carbon dioxide with 20% oxygen at 77°F. (25°C.). An increase in pH of 0.10 resulted after two hours, 0.21 after six hours, and 0.61 after 20 hours. There thus results an indirect effect of carbon dioxide on the tissue whereby the sap becomes more alkaline. In a later paper Thornton¹²⁹ showed that when green bananas were exposed to the influence of carbon dioxide, a reduction in ascorbic acid content of the fruit was brought about. For example, from 3 to 5% carbon dioxide accumulation from respiration caused a reduction of from 10 to 20% in ascorbic acid content; 8% carbon dioxide added to the atmosphere caused a reduction of from 30 to 50%; 24% carbon dioxide a reduction of from 42 to 80%; and 60% carbon dioxide

¹²⁴ J. W. Mitchell and P. C. Marth, *Botan. Gaz.*, 106, 199 (1944).

¹²⁵ J. W. Mitchell, *private communication*.

¹²⁶ R. Gane, *New Phytologist*, 36, 170 (1937).

¹²⁷ N. C. Thornton, *Contrib. Boyce Thompson Inst.*, 5, 371 (1933).

¹²⁸ N. C. Thornton, *ibid.*, 5, 403 (1933).

¹²⁹ N. C. Thornton, *ibid.*, 13, 201 (1943).

brought about a reduction of from 66 to 85%. This loss was complete since no dehydroascorbic acid was found upon reduction with hydrogen sulfide.¹³⁰

While Thornton's results indicate that carbon dioxide was effective in reducing the ascorbic acid content of green fruit, the gas had little effect upon this vitamin in yellow, ripe fruit. Furthermore, removal of bananas from a carbon dioxide rich atmosphere to a normal atmosphere at any stage of treatment resulted in rapid recovery of ascorbic acid to a level approximately that of untreated fruit of the same stage of ripeness. He found that, following the reduction of ascorbic acid in the early stages of ripening, there resulted—with continuous carbon dioxide treatment during the course of ripening—a gradual increase in the ascorbic acid content of the fruit, until at the brown peel stage the quantity of this vitamin approached that present in untreated fruit.

Several workers have found that atmospheres low in oxygen are detrimental to normal ripening. Early work by Bailey¹³¹ showed that complete lack of oxygen had an inhibiting action on ripening. Scurti¹³² found that ripening was retarded when the fruit was kept at 64.4°F. (18°C.) in an atmosphere containing 2.5% oxygen, or at 75.2°F. (24°C.) with 5% oxygen, or at 89.6°F. (32°C.) with 10% oxygen. In every case the balance of the gas was nitrogen. When the fruit was removed from this atmosphere, ripening proceeded in a normal manner. Kidd and West,¹³³ on the other hand, stored bananas in containers with 2.5% and 5% oxygen and found that they ripened as fast as the controls stored in air. These same workers found that an increase in oxygen content of the atmosphere of from 30 to 50% above that of normal air accelerated ripening. The respired carbon dioxide was constantly removed from the containers in which the fruit was stored.

Gane¹³⁴ showed that in an atmosphere of 10% oxygen, 10% carbon dioxide, and 80% nitrogen, respiration is reduced to 80% of the values obtained in air; with one sample, the climacteric was delayed and did not occur within the period of observation.

¹³⁰ N. C. Thornton, *ibid.*, 14, 295 (1946).

¹³¹ E. M. Bailey, *J. Biol. Chem.*, 1, 355 (1905-6).

¹³² F. Scurti, *Rev. freddo.*, 24, 111 (1938).

¹³³ F. Kidd and C. West, *Dept. Sci. Ind. Research (Brit.)*, *Rept. Food Invest. Board*, 1932, 68.

¹³⁴ R. Gane, *New Phytologist*, 35, 383 (1936).

A recent paper by Leonard^{134a} is of interest in regard to the effect of different concentrations of oxygen on ripening of the banana. Leonard investigated the respiration of "heavy 3/4 full" Gros Michel fruit at 53°F. (11.7°C.) during 19 days from harvesting in an atmosphere saturated with water vapor and containing various concentrations of oxygen, with carbon dioxide absent. Respiration was subsequently followed in air at 68°F. (20°C.) to determine the effect on ripening of the previous storage environment. It was found that, in decreasing concentrations of oxygen below that in air, the rate of liberation of carbon dioxide was reduced. The internal concentration of carbon dioxide showed little difference in the various external oxygen concentrations at 53°F. (11.7°C.). Internal oxygen concentration showed a linear relationship with the external oxygen concentration.

Leonard found no acceleration of the time of incidence of ripening in oxygen concentrations greater than air. Normal ripening changes appeared to take place at 68°F. (20°C.) after the period at 53°F. (11.7°C.), whatever the previous oxygen environment.

The effect of carbon dioxide and oxygen upon bananas has considerable practical significance in the proper shipment, ripening, and storage of the fruit. Thus, Scurti¹³² and Zavanju¹³⁵ show that mixtures of 95% nitrogen, 2.5% oxygen, and 2.5% carbon dioxide at 64.4°F. (18°C.) caused a slowing down of the metabolism of the fruit with detrimental effects on odor and taste. At higher temperatures, the biochemical changes were accompanied by the development of unpleasant odors or tastes. Wülfert¹³⁶ also found that atmospheres high in nitrogen were detrimental to normal ripening. He was unable to ripen fruit in an atmosphere of nitrogen, although there was a limited carbon dioxide production by the fruit.

Wardlaw¹³⁷ made an extended study on the refrigerated gas storage of bananas. "Heavy 3/4 full" fruit was rapidly cooled to 53°F. (11.6°C.) and held at this temperature for 20 days in an atmosphere containing 5% carbon dioxide and from 7 to 12%

^{134a} E. R. Leonard, *Ann. Botany*, 11, 299 (1947).

¹³⁵ A. Zavanju, *Rev. Freddo.*, 23, 83 (1937).

¹³⁶ K. Wülfert, *Biochem. Z.*, 302, 232 (1939).

¹³⁷ C. W. Wardlaw, *Imp. Coll. Trop. Agr. Trinidad, Mem. Low Temp. Research Sta.*, No. 15, 1940; *Trop. Agr. (Trinidad)*, 17, 103 (1940).

oxygen. There was a noticeable retardation of ripening without injurious effects. Bananas exposed to such a temperature often exhibit the effects of chilling (Section G), but the gas-stored fruit did not exhibit such effects. Severe chilling injury was, however, noted in the control fruit. It should be noted in this connection that Wardlaw's controls received 10 air changes per hour, while the gas-treated fruit received 2.6 changes per hour. This may have influenced the chilling of his controls, although he does not mention this fact.

Wardlaw found that the gas-stored fruit ripened in a normal manner with satisfactory palatability and bouquet. A reduction in the oxygen concentration from 21% to 12% did not afford adequate retardation of ripening during cool storage, whereas a reduction to 6% did retard ripening without injurious effects. If incipient ripening has already started, refrigerated gas storage does not sufficiently retard ripening to be of any practical importance.

In commercial practice the accumulation of carbon dioxide within a confined space to control the onset of ripening would present considerable difficulty because of gas leakage.^{137a} It would require a gastight compartment, or at least a space sufficiently airtight to permit a reasonably accurate control of the composition of the air. The construction of such a compartment would probably entail considerable expense and perhaps certain construction difficulties. Barnell was apparently troubled by gas leakage in his large-scale experiments, and made several attempts to overcome this by changes in design. However, Barnell's work was interrupted by the war.

During storage in an atmosphere containing a concentration of carbon dioxide higher than in normal air, there is an increase of carbon dioxide in the tissues of the fruit, but when such fruit is returned to a normal atmosphere the carbon dioxide rapidly escapes from the tissues.

Wardlaw¹³⁷ observed "gas injury" in fruit that had occasionally been subjected to high concentrations of carbon dioxide and low concentrations of oxygen. The peel of such fruit was spotted with minute, nonsunken grayish brown specks, accompanied by a slight grayish darkening of the peel.

^{137a} E. R. Leonard, *Trop. Agr. (Trinidad)*, 23, 190 (1946).

From his researches, Wardlaw believes that the use of artificial cooling in conjunction with artificial atmospheres containing approximately 5% carbon dioxide and from 5 to 7% oxygen should make it possible to effect overseas transport of bananas during a voyage of at least 16 days, of a good grade of Gros Michel fruit considerably heavier than "3/4 full" and even surpassing "heavy 3/4 full" from certain environments.

As another means of holding fruit in storage at 53°F. (11.7°C.), Barnell coated the bananas with a solution of white rum (10 gallons), castor oil (3 pints), and shellac (1.88 pounds).^{137a} The rum is probably used as a solvent and there was probably a good reason for not utilizing ethyl or methyl alcohol or isopropyl alcohol. Barnell found that if the storage period of fruit dipped in this solution was not more than a few days beyond the period of the untreated fruit, the treated fruit would remain green at 53°F. (11.7°C.) and subsequently ripen more slowly to give fruit of better appearance, with delayed onset of anthracnose, free from "chilling" symptoms, and of good eating quality.^{137a}

G. Effects of Chilling

Chilling is an unhealthy condition induced by exposure to unsuitably low temperatures during transportation or storage. Wardlaw and McGuire¹³⁸ believe that the unhealthy conditions in bananas brought about by chilling are not unlike the premature physiological breakdown of Bramley seedling apples stored at temperatures below 36°F. (2.2°C.).

Chilling has been described by many writers. Wardlaw and McGuire¹³⁸ state that it is difficult to recognize in the green banana. Slocum¹³⁹ has shown that chilling causes a gradual closing of the stomata in green fruit, and does not reach culmination until a day or two after exposure. Even at that time closing is only partial in most cases. Baker¹⁴⁰ has identified chilling in a general way by

¹³⁸ C. W. Wardlaw and L. P. McGuire, *Trop. Agr. (Trinidad)*, 8, 139 (1931).

¹³⁹ A. H. Slocum, *Effect of Low Temperature on Cell Structure*. United Fruit Co., Research Dept. Bull. No. 48, 1933.

¹⁴⁰ J. Baker, *Dept. Sci. Ind. Research (Brit.)*, *Food Invest. Board Spec. Rept.*, No. 38, 1930.

an increased development of brown streaks in the subepidermal tissues.

During ripening, chilling is recognized by such abnormalities as: (1) delayed ripening, or in some cases complete failure to ripen; (2) hardening of the central placenta (more pronounced in the Cavendish than in the Gros Michel); (3) assumption of a dull yellow color; and (4) in the Gros Michel, the dull yellow color is replaced by a dull russet hue which later darkens and is rendered more unsightly by the presence of black blotches and patches soft to the touch. Sometimes the fruit will show a characteristic dark brown mottling, apparently associated with a dehydration of the tissues. Russetting is not so noticeable in the Cavendish, and according to Wardlaw and McGuire¹³⁸ chilling is more difficult to recognize in that variety than in the Gros Michel. Chilling also results in a loss of banana flavor, although Poland and Wilson¹⁴¹ report in their experiments that chilling did not impair the taste except in the case of fruit that was so severely chilled that the ripening process was permanently stopped. These workers showed that chilled fruit did not contain significantly less sugar than the control fruit (Table 7).

Barnell and Barnell¹⁴² have postulated that the characteristic colors of chilled fruit are caused by oxidized tannin in the peel. The mechanism of the process is probably as follows. Internal oxygen concentration of chilled fruit is high, perhaps resulting in a smaller acetaldehyde formation. With less acetaldehyde, a smaller amount of tannin may be rendered nonastringent; of the remaining tannin, that in the peel may be oxidized to give the colors noticed in chilled fruit.

Leonard and Barnell¹⁴³ state that extreme chilling results in a very considerable retardation of ripening, the starch hydrolysis mechanism being particularly affected. Barnell's¹⁴⁴ studies of the carbohydrate metabolism of bananas stored at 53°F. (11.7°C.) are of

¹⁴¹ G. L. Poland and R. M. Wilson, *Banana Chilling Studies. I. Effect of Low Temperatures on Appearance and Edibility*. United Fruit Co., Research Dept. Bull. No. 46, 1933.

¹⁴² H. R. Barnell and E. Barnell, *Ann. Botany*, 9, 77 (1945).

¹⁴³ E. R. Leonard and H. R. Barnell, *Imp. Coll. Trop. Agr. Trinidad, Mem. Low Temp. Research Sta.*, No. 11, 1934.

¹⁴⁴ H. R. Barnell, *Ann. Botany*, 7, 1 (1943).

interest in connection with chilling. He found that carbohydrate changes, although greatly retarded, proceeded in the same general direction and were of the same general type as in fruit ripened at higher temperatures. Eventually, the composition of the pulp with respect to starch and sugars was indistinguishable from that of a

TABLE 7. COMPARISON OF VISIBLE INJURY TO BANANAS CHILLED AT 30°F., WITH SUGAR CONTENT AND COLOR CHANGES AFTER RIPENING FOR SIX DAYS¹⁴¹

Lot No.	Time exposed at 30°F., hours	Degree of dullness	Color No. ^a		Sugar content, per cent of fresh pulp	
			Chilled	Control	Chilled	Control
1	8	Slight	5-6	5	20.57	21.16
2	8	Slight	4-5	5	19.99	20.41
1	12	Sl. med.	4-5	5	19.71	20.14
2	20	Severe	4-5	5	20.07	20.03
1	24	Medium	4-5	5	20.03	19.64
1	28	Medium	4-5	5	19.87	21.09
2	28	Severe	4-5	4-5	19.04	20.86
1	32	Medium	4	4-5	20.03	19.53
2	32	Severe	4-5	5	20.16	20.11
1	36	Severe ^b	4	5	19.75	20.41
2	44	Severe	4-5	5	19.65	20.81
1	52	Severe	4	5-6	20.31	21.12
1	56	Severe	4	5-6	20.30	21.07
1	72	Severe	3-4	6	19.63	20.94

^a For explanation of color number, see color plate, page 108.

^b All brown.

fruit accepted as "eating ripe." There was, however, considerable divergence in the time of occurrence of starch-sugar changes from the time of occurrence of other processes in the fruit. For example, when the peel had changed from green to dull yellow with bronze colors appearing, the percentage of starch in the pulp was still high, and the sugars low. When the starch and sugar values had reached the "eating ripe" levels, the peel was starting to blacken and the appearance of the chilled fruit was unprepossessing. Storage at 53°F. (11.7°C.) did not produce any marked deviations in the type of carbohydrate catabolic processes of the ripening banana from those at higher temperatures, but the speed of such processes was retarded.

In an earlier paper Barnell¹⁴⁵ noted that "chilling" produced fruit of poor eating quality and, in general, the pulp of such fruit had a higher starch content, lower sugar, more acid, and more glycosidic glucose (perhaps derived from tannins) than the pulp of good quality fruit. By "chilled" fruit, Barnell refers to fruit that has been held at 53°F. (11.7°C.). Apparently Poland and his co-workers¹⁴¹ designate chilled fruit as that subjected to considerably lower temperatures. Any differences in results between Barnell's studies and those of Poland can probably be attributed to the wide divergence in temperatures to which the fruit was subjected.

Harris and Poland¹⁴⁶ found that slight chilling (where the peel was only slightly dulled) had no deleterious effect on the ascorbic acid content of the fruit. When chilling was severe enough to cause the peel to become black and the pulp soft upon ripening, loss of ascorbic acid amounted to over 50%.

Barnell and Barnell¹⁴⁷ and Scurti and Pavarino¹⁴⁸ have noted that tannins remain high in chilled fruit.

Of particular interest is the fact that concentrations of carbon dioxide and oxygen are different in chilled fruit from those in normal fruit.¹⁴⁹ Internal concentration in chilled fruit does not show such large changes as in fruit subjected to shorter periods of temperatures of 53°F. (11.7°C.). The concentration falls relatively slowly, does not reach such low values, and recovery after the fruit has started to color is relatively slight. Such observations have been limited, and Barnell and Barnell¹⁴⁷ point out that any hypothesis must be tentative. It is apparent, however, that anaerobic respiration may play a smaller part in chilled than in unchilled fruit, since oxygen concentration remains high in the former.

Terms used in the banana trade in the United States to describe chilling are somewhat different from those used in Great Britain. The terminology of Wardlaw and McGuire has already

¹⁴⁵ H. R. Barnell, *Ann. Botany*, 5, 608 (1941).

¹⁴⁶ P. L. Harris and G. L. Poland, *Food Research*, 4, 317 (1939).

¹⁴⁷ H. R. Barnell and E. Barnell, *Ann. Botany*, 9, 77 (1945).

¹⁴⁸ F. Scurti and G. L. Pavarino, *Ann. speriment. agraria Rome*, 15, 91 (1934).

¹⁴⁹ C. W. Wardlaw, *Imp. Coll. Trop. Agr. Trinidad, Mem. Low Temp. Research Sta.*, No. 15, 1940.

been described (see above). Poland and Wilson¹⁵⁰ use the following descriptive terms for fruit that has been chilled:

Slight dullness. A trace of dullness when the chilled fruit is compared side by side with unchilled fruit. This stage is not commercially important.

Medium dullness. Ordinarily, this condition would be detected by the average dealer or jobber. The fruit is salable, but not attractive.

Severe dullness. The peel is grayish yellow and "dead" looking. Sometimes the peel is greenish gray or brownish gray. Retailers may discard such fruit or sell it at a reduced price.

All brown. The peel is entirely brown, and often black. Such fruit is unmarketable.

Chilling renders the fruit susceptible to disfiguring by handling, or by packing materials. Thus, the fingers may split, the peel bursting along the ridges.

Poland and Wilson¹⁵⁰ exposed green fruit out-of-doors during appropriate weather and then ripened the fruit to the stage suitable for delivery. If the fruit thus ripened had a medium dull color, it was considered unmarketable. Results are given in Table 8.

TABLE 8. TIME OF EXPOSURE (IN HOURS) AT DIFFERENT TEMPERATURES CAUSING INJURY OF COMMERCIAL IMPORTANCE¹⁵⁰

Color of fruit when exposed	Temperature of exposure			
	45°F.(7.2°C.)	40°F.(4.4°C.)	35°F.(1.7°C.)	30°F.(-1.1°C.)
Green	12	26	15	18
Turning	14	18	12	14
Green tip	18	12	12	6
All yellow	12	12	18	12

According to the researches of Poland and Wilson, there is no particular stage of ripeness at which the fruit is immune or especially susceptible to chilling injury. There is a greater tendency for yellow fruit to darken after 24 hours' exposure than for the less ripe fruit.

Using the cryoscopic method, and calculating from osmotic pressure data, Poland and Wilson determined the freezing point of the sap of the peel of normal and chilled bananas (Table 9).

¹⁵⁰ G. L. Poland and R. M. Wilson, *Banana Chilling Studies. I. Effect of Low Temperatures on Appearance and Edibility*. United Fruit Co., Research Dept. Bull. No. 46, 1933.

The data in Table 8 seem to contain some inconsistencies; in particular, one wonders why 26 hours' exposure was required to cause injury to green fruit at 40°F. (4.4°C.), but only 12 hours at 45°F. (7.2°C.), and 18 hours at 30°F. (−1.1°C.). The investigators were unable to explain these differences.¹⁵¹

TABLE 9. FREEZING POINTS OF PEEL SAP OF NORMAL AND CHILLED BANANAS¹⁵⁰

Condition of fruit	Chilled	Control
FAILED TO RIPEN		
Green fruit before chilling	30.96°F. (−0.58°C.)	30.96°F. (−0.58°C.)
After 48 hours at 30°F. (−1.1°C.)	31.01°F. (−0.55°C.)	31.03°F. (−0.54°C.)
8 days after chilling	30.72°F. (−0.71°C.)	30.13°F. (−1.04°C.)
SUBSEQUENTLY RIPENED		
Green fruit before chilling	30.97°F. (−0.57°C.)	30.97°F. (−0.57°C.)
After 48 hours at 30°F. (−1.1°C.)	31.03°F. (−0.54°C.)	30.89°F. (−0.62°C.)
5 days after chilling	29.39°F. (−1.45°C.)	30.50°F. (−1.39°C.)

Wardlaw and McGuire,¹⁵² using higher temperatures, found that chilling would occur in Gros Michels after an exposure of 14 days at 52°F. (11.1°C.), and after 9 days at 51°F. (10.6°C.). However, these workers established that rapid cooling to 53°F. (11.7°C.) within 12 days may be practiced without danger of chilling during the usual steamship voyage of 16 to 20 days. Chilling is a cumulative effect of duration of exposure, and not the result of rapid cooling to a definite low temperature.

Slocum¹⁵³ has made a careful study of changes in the morphology of the fruit during chilling. Moderate or severe chilling causes a more or less complete closure of all or a part of the stomata.

¹⁵¹ *Private communication* from G. L. Poland.

¹⁵² C. W. Wardlaw and L. P. McGuire, *Trop. Agr. (Trinidad)*, 8, 139 (1931).

¹⁵³ A. H. Slocum, *Effect of Low Temperature upon Cell Structure*. United Fruit Co., Research Dept. Bull. No. 48, 1933.

This closure is more complete in ripe fruit than in green fruit and takes place more rapidly. Within 24 hours after severe chilling, dark, granular bodies will generally start to appear within a majority of the cells of the epidermis. This phenomenon is apparently caused by death of the protoplasm, and interferes with the natural transparency of the epidermis. Probably this is responsible for much of the "smoky" or dull appearance of the peel so characteristic of chilled fruit. Barnell and Barnell¹⁵⁴ postulate that the well-known colors of chilled fruit are caused by oxidized tannin in the peel.

With death of the protoplasm and appearance of granular bodies, the guard cells of certain stomata begin to develop a reddish brown discoloration which gradually extends to adjacent cells. Only the cell walls appear to be discolored. Finally, there sometimes results, in very severe chilling, an unevenness of cuticle quite likely due to irregular shrinkage and to partial desiccation of the epidermal cells.

The first noticeable effect on the chlorenchyma, in the case of green fruit, is a rapid disintegration and disappearance of the chloroplastids. There is not, however, an immediate destruction of chlorophyll, but merely its dissemination throughout the cell. Except in the most severe cases of chilling, the normal green color of the peel is very little affected at this stage. The second stage of chilling in green fruit corresponds to the first stage in ripe fruit.

The first stage of chilling in ripe fruit is generally marked by a disorganization of the protoplasm. The whole cell cavity becomes filled with a very finely granulated material apparently held in suspension by the cell fluid which imparts a grayish opacity to the whole region. This opacity serves to mask any traces of green or yellow pigment that may still remain, and is apparently chiefly responsible for the dull leaden color of badly chilled fruit. Later on, the finely diffused granular material starts to come out of suspension and to coalesce in relatively large opaque particles, and the cell fluid again becomes transparent. This phase corresponds to the "all brown" stage of heavy chilling.

¹⁵⁴ H. R. Barnell and E. Barnell, *Ann. Botany*, 9, 77 (1945).

In the case of the latex system, there is a premature clearing of the latex in green bananas caused by the precipitation of the globules. Because of this, there is a restricted exudation of the latex from chilled, green fruit. The walls of the latex vessels and the precipitate of gummy material become more or less discolored. In very severe cases, the discoloration will extend to the fibro-vascular bundles.

CHEMICAL CHANGES DURING RIPENING

Although the fruit is never allowed to ripen on the tree for commercial purposes, studies have been undertaken relative to the composition of fruit on the plant. An early paper by Ricciardi¹⁵⁵ is of interest in this connection, and his statement regarding the sugars of the fruit is pertinent: "...saccharine material is almost wholly cane sugar [in the green fruit], while that of the harvested ripe fruit consists of four fifths invert sugar and one fifth sucrose." Leonard and Barnell¹⁵⁶ indicate that, during the development of the bunch, sugars remain at a very low concentration, while starch is rapidly accumulated. The rate of accumulation of both starch and dry matter in the pulp is greater during the two to three weeks following the age level at which the fruit would normally be harvested for export than during the weeks preceding this age level. Bourdouil¹⁵⁷ showed that reducing sugars are transformed into starch during development of the fruit. When the fruit has reached the cutting stage, the starch is changed to sucrose during subsequent maturation.

Belval¹⁵⁸ recognizes two distinct periods in the growth of the fruit. The first period is that of starch reserve in the course of which the fruit, always low in soluble sugar, fixes its starchy reserve at the expense of reducing sugars. Since sucrose is undoubtedly utilized less rapidly than reducing sugars, the former becomes predominant. The next period is one of maturation, and here soluble sugars are formed from part of the starch, the former

¹⁵⁵ L. Ricciardi, *Compt. rend.*, 95, 393 (1882).

¹⁵⁶ E. R. Leonard and H. R. Barnell, *Imp. Coll. Trop. Agr. Trinidad, Mem. Low Temp. Res. Sta.*, No. 11, 1939.

¹⁵⁷ C. Bourdouil, *Rev. botan. appl. agr. trop.*, 11, 656 (1931).

¹⁵⁸ M. H. Belval, *Rev. gén. botan.*, 44, 513 (1932).

being transformed into sucrose while the latter is hydrolyzed to invert sugar.

Belval¹⁵⁸ studied the transformation of sugar and the disappearance of starch in the banana plant itself during fruit formation. The first product of chlorophyllin assimilation possible to detect in the edges of the leaves is sucrose. This sugar, in its progressive transformation into invert sugar, finally reaches the central nerve of the leaf. Inversion of sucrose continues all along the leafstalk so that sucrose, which is dormant in the vein, forms but a small portion of the sugars in the base of the leafstalk. At the leafstalk base, the mixture of soluble sugars enters into the normal flowerstalk without having undergone significant modifications, and then penetrates into the fruit.

With regard to acidity, Barnell¹⁵⁹ did not find an initial rise in the pulp. However, simultaneously with the synthesis of starch, a continuous fall in acidity occurred throughout development until starch hydrolysis began, when rising values for acid content were observed.

Barnell showed that with age the fruit increased in size and weight, in total dry matter content, and in water. About 125 days after emergence, indications of incipient ripening appeared, based on the carbohydrate composition of the fruit pulp. After 100 days, the percentage of starch decreased and the concentration of soluble sugars increased. During this period it appeared that the amount of starch hydrolyzed exceeded the increase in soluble sugars. This may be caused by a high rate of carbon loss in respiration.

During the ripening of the harvested fruit under controlled temperature and humidity conditions, definite chemical and physical changes are brought about. Many of these changes have been studied quite thoroughly by numerous investigators, while the mechanism of other changes taking place are little known at the present time.

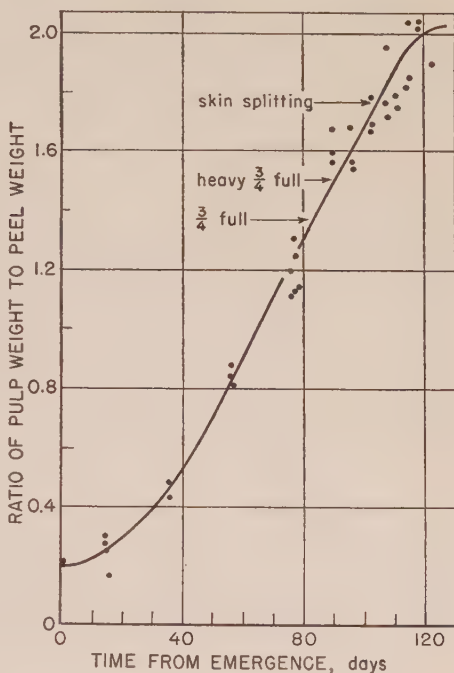
A. Pulp-to-Peel Ratio

During ripening of the fruit, the pulp increases in weight due to an increase in water content. This water is obtained from

¹⁵⁸ H. R. Barnell, *Ann. Botany*, 4, 39 (1940).

the peel, and probably also from the stalk.¹⁶⁰⁻¹⁶² Because of this, the peel loses weight, and this differential behavior will cause a difference in ratio between pulp and peel weights as the fruit ripens.

Fig. 18. Ratio of the fresh weight of pulp to fresh weight of peel for Gros Michel bananas. The smooth curve was drawn by eye through the points of the graph. The break in the curve indicates the end of the scale of ages of the fingers in days from emergence of the bunch and the beginning of the scale based on the arbitrary age of "80" days assigned the bunches selected as having "standard $\frac{3}{4}$ full" English grade fruit.¹⁶⁶



This ratio has been termed the "coefficient of ripeness" and was apparently first used by Tallarico¹⁶³ as an index of fruit maturity. Since that time several other workers have used the same index.¹⁶⁴⁻¹⁶⁶ Wolfe¹⁶⁷ has criticized it as "unreliable as well as

¹⁶⁰ H. C. Gore, *J. Agr. Research*, 3, 187 (1914).

¹⁶¹ A. J. M. Smith, *Dept. Sci. Ind. Research (Brit.), Rept. Food Invest. Board*, 1932, 138.

¹⁶² F. C. Stratton and H. W. von Loesecke, *Plant Physiol.*, 6, 361 (1931).

¹⁶³ G. Tallarico, *Arch. farmacol. sper.*, 7, 27 (1908).

¹⁶⁴ E. M. Bailey, *J. Am. Chem. Soc.*, 34, 1706 (1912).

¹⁶⁵ C. Bourdoulil, *Bull. soc. chim. biol.*, 11, 1130 (1929).

¹⁶⁶ C. W. Wardlaw, E. R. Leonard, and H. R. Barnell, *Ann. Botany*, 3, 845 (1939).

¹⁶⁷ H. S. Wolfe, *Botan. Gaz.*, 92, 337 (1931).

insensitive." There is some question as to whether Wolf's condemnation is justified. Barnell¹⁶⁸ has presented further data on the pulp-to-peel ratio, based on carefully controlled experiments (Table 10).

In Table 10, the lower section shows the data obtained during the ripening of the fruit removed from low-temperature storage before any "chilling" occurred. It will be seen that the pulp-to-peel ratio increased slowly in fruit held in cold storage, and that the

TABLE 10. VARIATION IN THE PULP-TO-PEEL RATIO DURING STORAGE AND RIPENING OF BANANAS¹⁶⁸

Days from cutting	$\frac{3}{4}$ full fruit		Days from cutting	Heavy $\frac{3}{4}$ full fruit	
	Temp., °F.	Pulp-to-peel ratio		Temp., °F.	Pulp-to-peel ratio
0	80-85	1.48	0	80-85	1.60
20 hrs.	80-85	1.48	16 hrs.	80-85	1.62
26 hrs.	53	1.48	23 hrs.	53	1.61
3	53	1.51	2	53	1.64
6	53	1.48	4	53	1.63
10	53	1.48	6	53	1.60
14	53	1.49	9	53	1.64
17	53	1.58 ^a	11	53	1.65
19	53	1.63	14	53	1.77 ^a
21	68	1.65	16	68	1.82
23	68	1.69	17	68	1.69
25	68	1.89	19	68	1.75
27	68	2.20	21	68	2.06
29	68	2.38	24	68	2.46
31	68	2.50	26	68	2.79
33	68	2.67	—	—	—
16	68	1.51	9	68	1.63
18	68	1.53	11	68	1.60
20	68	1.69	13	68	1.70
22	68	1.87	16	68	1.97
24	68	2.04	18	68	2.16
26	68	2.28	—	—	—
28	68	2.42	—	—	—

^a Indicates that the value and those following it in the same column were obtained from fingers of the lower rows of the third hands of the bunch sampled; preceding values were obtained from upper row of fingers.

¹⁶⁸ H. R. Barnell, *Ann. Botany*, 5, 607 (1941).

rate of increase was somewhat accelerated when the fruit was placed in ripening rooms. There was a relatively sudden rise from values of 1.80 to 1.90 to values above 2.00 when the fruit became "ripe." Barnell found that there was close agreement on the whole, between the times indicated for the attainment of eating-ripe and the pulp-to-peel ratio. "Palatability depends on the composition of the fruit; therefore it will be, in general, at its optimum quality a day or so later than suggested by full yellow skin coloration and by 'coefficient of ripeness' of 2.0."¹⁶⁸

With regard to chilled fruit (*i.e.*, fruit held at too long a period at low temperatures for subsequent ripening), there appears to be a difference in ratio between such fruit and unchilled. Apparently there is a considerable passage of water from the stem to the pulp, or a reduced transpiration rate, or both, in chilled fruit. The pulp of chilled fruit retains more water during ripening than unchilled for approximately similar total losses by the peel, so the general level of the pulp-to-peel ratio values for chilled fruit during ripening are higher than for unchilled (Table 10).

B. Respiration

The problem of respiration is one of considerable complexity. The fruit continues to respire when removed from the tree, evolving carbon dioxide along with ethylene and probably small amounts of volatile esters. Any condition that radically changes this respiratory activity and thereby alters the normal metabolism of the fruit, will have detrimental effects upon its final quality.

Some of the early workers believed that the evolution of carbon dioxide was due to fermentation. Chatin,¹⁶⁹ for example, mentions this in a paper published in 1864. One of the earliest painstaking studies of the respiration of the banana was reported in a voluminous paper by Gerber¹⁷⁰ who found that the respiration of the fruit was characterized at low temperatures by a respiratory quotient (RQ) of less than unity (0.58), and that the RQ increased to a peak of 0.94 during ripening. This was followed by a decrease to 0.63. At elevated temperatures, the RQ increased to

¹⁶⁹ M. Chatin, *Compt. rend.*, 58, 576 (1864).

¹⁷⁰ M. C. Gerber, *Ann. sci. nat. Botan.*, 4, 1 (1896).

3.88 in the overripe fruit. Gerber studied separately the respiration of the pulp and of the peel, and found that the RQ of the peel was lower than that of the pulp. Langworthy and Miller¹⁷¹ report an average RQ of 1.04 during ripening.

In general, the trend of respiration is an initial steady, relatively low rate for green, unripe fruit, followed by a rapid rise during the early ripening period. The ripe and overripe fruit show a fairly steady, but usually slowly rising rate until the peel becomes completely brown and serious fungal wastage takes place, when a

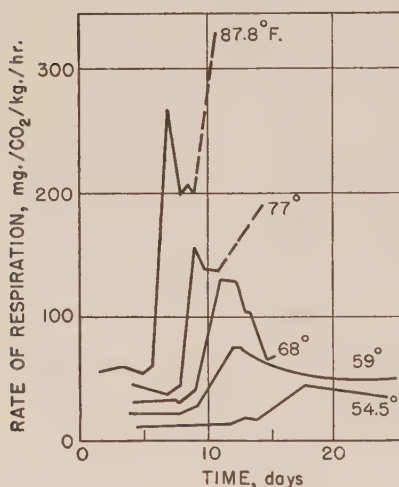


Fig. 19. The rate of production of carbon dioxide by bananas (initially unripe) at different temperatures. The curves at 77 and 87.8°F. are terminated by mold growth indicated by the broken lines.¹⁷⁸

final rise may occur (Fig. 19). The period of rapid increase in carbon dioxide liberation is spoken of as *the climacteric*. According to Leonard,¹⁷² it is essentially a transition phase in which the tissues are passing from a low level of metabolic activity to a higher one. The time of duration of the climacteric is an exponential function of temperature.¹⁷³

As would be expected, respiration varies with the temperature. The following data obtained from green fruit by Gane¹⁷³ indicate the general trend.

¹⁷¹ C. F. Langworthy and R. D. Milner, *Yearbook U. S. Dept. Agr.*, 1912, 293.

¹⁷² E. R. Leonard, *Ann. Botany*, 5, 89 (1941).

¹⁷³ R. Gane, *New Phytologist*, 35, 383 (1936).

Temperature		Respiration rate, mg. CO ₂ /kg./hr.
°F.	(°C.)	
32°	(0°)	7.1
41°	(5°)	10.0
54°	(12.5°)	18.5
59°	(15°)	23.6
68°	(20°)	35.8
88°	(31°)	61

Olney¹⁷⁴ reported that at 53.6°F. (12°C.) respiration was reduced to about one third of that at 68°F. (20°C.), a value not greatly different from Gane's data given above when the probable variation in fruit used by the two investigators is considered. Wardlaw¹⁷⁵ found that under conditions of rapid cooling from tropical temperatures to 53°F. (11.7°C.) with carbon dioxide accumulation and oxygen depletion in closed containers, the respiration rate of the fruit fell off rapidly from an initial value of 35–40 to 8–10 milligrams per kilogram per hour.

Gane¹⁷³ followed the change in sugar along with the respiration of the fruit (Table 11). As soon as ripening starts, respira-

TABLE 11. RESPIRATION OF RIPENING BANANAS AND SUGAR CONTENT OF THE PULP (FRUIT RIPENED AT 59°F.)¹⁷³

Day	Respiration, mg. CO ₂ /kg./hr.	Percentage of fresh weight		
		Reducing sugars	Sucrose	Total sugars
1	—	0.171	0.572	0.743
2	23.4	0.251	0.659	0.910
3	22.6	0.217	0.642	0.859
4	21.7	0.236	0.608	0.844
5	21.7	0.291	0.637	0.928
6	23.7	0.310	0.707	1.017
7	24.1	0.606	0.874	1.480
8	25.2	0.432	0.804	1.236
9	32.5	0.621	0.922	1.543
10	40.2	0.593	1.050	1.643
11	52.0	1.125	2.636	3.761
12	62.2	1.361	4.076	4.437
13	73.0	1.738	5.764	7.502

¹⁷⁴ A. J. Olney, *Botan. Gaz.*, 82, 415 (1926).

¹⁷⁵ C. W. Wardlaw, *Trop. Agr. (Trinidad)*, 7, 103 (1940).

tion begins to increase and there is an increase in the acidity of the pulp. This fall in pH continues until well after the peak of respiratory activity, and reaches a maximum pH of 4.34. Further changes in pH are small and the rise which follows occurs at the time when the characteristic aroma is produced. At the peak of respiratory activity, a change in color from green to yellow begins to be visible in the peel.

The heat evolved by the fruit during ripening is of considerable commercial importance. Early work by Langworthy and

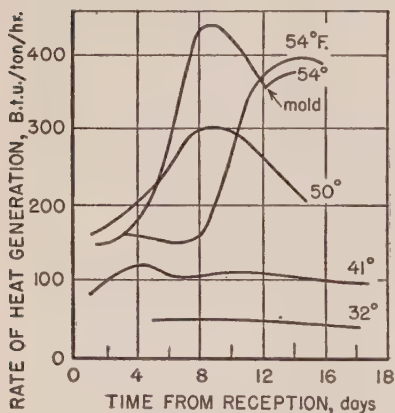


Fig. 20. Heat production by bananas at different temperatures as calculated from CO_2 production.¹⁷⁸

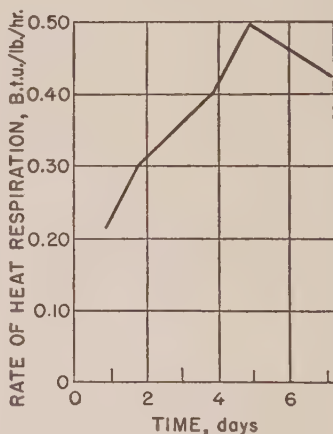


Fig. 21. The heat of respiration of bananas ripened from one to seven days at 70°F.

Milner¹⁷⁶ showed that the heat produced amounted to one calorie per kilogram of fruit per hour at its greatest ripening intensity. This value may be in error because unpublished discussion of their results seem to indicate a value of 0.5 calorie. Hofbauer¹⁷⁷ gives values of from 0.28 to 0.32 cal./kg./hr.; Olney¹⁷⁴ reports 0.3 cal./kg./hr. by ripening bananas at 68°F. (20°C.). In engineering units, Smith¹⁷⁸ reports that at the time of arrival at port of discharge, bananas have a heat production of the order of 150 B.t.u.

¹⁷⁶ C. F. Langworthy and R. D. Milner, *Yearbook U. S. Dept. Agr.*, 1912, 293.

¹⁷⁷ G. Hofbauer, *Mitt. staatl. tech. Versuchsanst.*, 16, 119 (1927).

¹⁷⁸ A. J. M. Smith, *Dept. Sci. Ind. Research (Brit.)*, *Rept. Food Invest. Board*, 1932, 145.

per ton per hour. This may increase within a few days, if the fruit continues to be stored at 53° to 54°F. (11.7° to 12.2°C.), to a maximum of 450 B.t.u./ton/hr. These figures very closely approach those obtained by Gane.¹⁷³ Using Gane's data on page 73, and multiplying by 10, the result is the heat produced in B.t.u. per ton per hour. This is based on the assumption that the respiration action involved is one of carbohydrate oxidation and that the production of carbon dioxide at the rate of one milligram per kilogram per hour corresponds to the rate of heat production of approximately 10 B.t.u. per ton per hour. It should also be mentioned that Gane found that fruit on the stalk gave the same values as detached hands.

Hofbauer¹⁷⁷ found the specific heat of bananas to be 0.72. Unpublished data by the Research Department of the United Fruit Company indicate values of 0.7720 ± 0.0618 for Jamaica fruit and 0.8033 ± 0.0532 for Tela fruit. These results are the average of eight determinations.

The internal concentration of gases (carbon dioxide and oxygen) will vary during the ripening period. Leonard and Wardlaw¹⁷⁹ found that when fruit was transferred from 85°F. (29.4°C.) to 53°F. (11.7°C.) there was a decrease in internal carbon dioxide and a considerable increase in oxygen. Then approximately steady levels were maintained during storage at 53°F. (11.7°C.); but on transferring to 68°F. (20°C.) or 65°F. (18.3°C.) transition effects were observed. This was followed by the establishment of new levels, *i.e.*, higher carbon dioxide and lower oxygen concentrations. With the onset of ripening, the internal concentrations of carbon dioxide and oxygen rose and fell, respectively. In this connection, the peak of internal carbon dioxide concentration closely approximated in time the peak of respiration rate. During the climacteric phase there was a recovery in oxygen concentration from minimal values, and a decline in carbon dioxide concentration from the peak value. The increased resistance to the movement of gases offered by the tissues as a result of ripening changes was attended by a decline in the oxygen concentration and an increase in carbon dioxide during senescence.

The preclimacteric trends in internal gas concentrations at

¹⁷⁹ E. R. Leonard and C. W. Wardlaw, *Ann. Botany*, 5, 379 (1941).

53°F. (11.7°C.) and at 68°F. (20°C.) or at 65°F. (18.3°C.) showed only small changes, but they were consistently in the direction of increasing concentrations of carbon dioxide. This indicated a changing rate of metabolism, and was confirmed by estimations of carbohydrate metabolites. In fruit held at 53°F. (11.7°C.), the onset of ripening was denoted by a slow rise in internal carbon dioxide concentration to a low maximum value in the nature of a sustained level. Internal oxygen concentrations slowly descended to a minimum value with the exception that this minimum value was attained after the peak in the internal carbon dioxide curve and was immediately followed by attainment of the "sprung" condition.*

The concentration of internal gases is considered of importance by many research workers in this field. Leonard and Wardlaw,¹⁷⁹ for instance, postulate that there may be threshold values of internal oxygen for different grades of fruit ripening at different temperatures, and that these values might be of critical importance in the initiation of ripening changes. Some data presented by these investigators would appear to lend support to this hypothesis. Changes in internal gas concentrations, and particularly that of oxygen, will in turn react on the metabolic changes in progress during maturation of the fruit. Such changes may account in part, according to Leonard and Wardlaw, for modifications in the metabolic trend during ripening.

C. Changes in Moisture Content during Ripening

Stratton and von Loesecke¹⁸⁰ have pointed out that the moisture content of the pulp increases as the fruit ripens, the additional water being derived from the carbohydrates utilized in respiration (Table 12). Barnell¹⁸¹ also found an increase in water content of the pulp during maturation, and stated that this may be taken as an approximation of the respiration rates of the tissues. Since loss of estimated carbohydrates was at times lower than rate of in-

* See page 30.

¹⁸⁰ F. C. Stratton and H. W. von Loesecke, *A Chemical Study of Different Varieties of Bananas during Ripening*. United Fruit Co., Research Dept., Bull. No. 32, 1930.

¹⁸¹ H. R. Barnell, *Ann. Botany*, 5, 217 (1941).

crease of water, it follows that sources other than carbohydrates were drawn upon in respiration metabolism of the fruit.¹⁸¹

Gore¹⁸² calculated the water formed by respiration and that utilized in the hydrolysis of starch, and found that, except when the fruit becomes overripe, the water formed in respiration does

TABLE 12. CHANGE IN MOISTURE CONTENT OF BANANAS DURING RIPENING¹⁸⁰ EXPRESSED AS PERCENTAGE OF FRESH PULP

Variety	Days in ripening room ^a							
	0	3	5	7	9	11	14	17
Gros Michel	74.4	75.6	75.4	75.9	76.4	77.4	—	—
Lady Finger	66.7	67.5	69.0	70.5	71.9	73.5	—	—
Lacatan	72.5	71.5	71.3	70.4	71.2	71.6	72.1	—
Plantain	63.0	62.8	64.6	64.1	62.3	63.2	63.8	67.9
Red banana ^b	71.8	70.3	71.3	72.2	73.3	74.2	—	—

^a Last figures in table represent fruit at full-ripe stage.

^b Unpublished data by J. T. Manion, United Fruit Co., Research Dept., 1933.

not equal that used in hydrolysis. He also points out the probable change in osmotic pressure with resulting transfer of water from peel to pulp.

Stratton and von Loesecke¹⁸³ have measured this transfer of water by means of osmotic pressure determinations. At the time of discharge from the ship (at Boston) the osmotic pressures of

TABLE 13. OSMOTIC PRESSURES OF DIFFERENT PARTS OF THE BANANA FRUIT BUNCH DURING RIPENING¹⁸³

Days in ripening room	Color	Osmotic pressure, atm.				
		Pulp	Peel	Neck	Crown	Stalk
0	Green	7.15	6.19	7.17	7.82	6.81
3	Very slightly green	16.91	9.29	7.41	6.55	6.10
6	Green tip	25.48	10.47	6.80	7.02	5.36
9	Slightly speckled	29.06	12.42	6.46	7.00	5.58

pulp and peel were approximately equal and therefore at equilibrium. As ripening progressed, there was a marked increase of pressure in the pulp with a lesser increase in pressure of the peel. This difference in pressure between pulp and peel resulted in a

¹⁸² H. C. Gore, *J. Agr. Research*, 3, 187 (1914).

¹⁸³ F. C. Stratton and H. W. von Loesecke, *Plant Physiol.*, 6, 361 (1931)

migration of water from the latter to the former. The pressure difference is explained by the fact that while starch, the major constituent of the pulp of green fruit, does not affect the pressure to any appreciable extent, hydrolysis of this starch to sugar during ripening causes an increase in osmotic pressure, and this increase

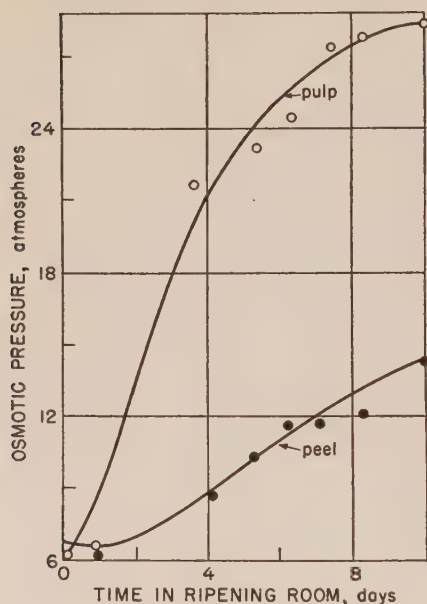


Fig. 22. The change in osmotic pressure of pulp and peel of bananas during ripening.

is in proportion to the sugar formed. The sugar content of the peel is much lower than that of the pulp. During ripening, there is, in general, a gradual decrease in order of osmotic pressure from the pulp to the stalk, indicating a transfer of water from other parts of the bunch of fruit to the pulp (Fig. 22).

D. Changes in Carbohydrates during Ripening

The most conspicuous change in the maturation of the banana is the conversion of starch to sugars. Wardlaw and Leonard¹⁸⁴ and Leonard and Barnell¹⁸⁵ give a broad picture of changes taking

¹⁸⁴ C. W. Wardlaw and E. R. Leonard, *Ann. Botany*, 4, 269 (1940).

¹⁸⁵ E. R. Leonard and H. R. Barnell, *Imp. Coll. Trop. Agr. Trinidad, Mem. Low Temp. Res. Sta.*, No. 11, 1939.

place during ripening. The first indications of ripening are in the placental region where the tissues become soft, acquire a honey color, and are sweet in taste. Ripening thus proceeds through the outer pulp to the peel. The distal or styler end of the fruit ripens slightly in advance of the proximal, stem end. There is a rapid disappearance of starch in the pulp. At this stage, the peel as a rule is still firm green and turgid, but the pulp has started to become soft.

Considerable research has been accomplished relative to the quantitative changes in the carbohydrates during ripening of the fruit. One of the earliest papers in this connection is that by Buignet¹⁸⁶ who recognized that changes in the proportion of carbohydrates and tannin took place during ripening. He states: "In the green banana, there is found, all at the same time, much starch and tannin, and these two principal constituents diminish progressively and simultaneously so that in the ripe banana not more than a trace of either one is found. The sugar present in their place is sucrose." Although Buignet was not entirely correct in his conclusions, he did recognize that fundamental changes in carbohydrate composition took place during ripening.

Corenwinder¹⁸⁷ presented quantitative data to show that during ripening nonreducing sugars increased which is not in agreement with the modern concept of ripening. Corenwinder's error in reporting an increase in reducing sugars may have been due to his analytical methods, and to his failure to destroy invertase. Mierau¹⁸⁸ appears to have been the first to point out that, since bananas contain invertase, erroneous results will be obtained upon analysis unless this enzyme is first inactivated. Mierau's results were unknown to Corenwinder.

Bridel and Bourdoul¹⁸⁹ believed that the quantity of sucrose formed was proportional to the starch disappearing.

Stratton and von Loesecke¹⁹⁰ ripened different varieties of bananas under controlled temperature and humidity conditions.

¹⁸⁶ M. H. Buignet, *Ann. chim. phys.*, 61, 233 (1861).

¹⁸⁷ B. Corenwinder, *Compt. rend.*, 88, 293 (1879).

¹⁸⁸ F. Mierau, *Chem.-Ztg.*, 17, 1002, 1021 (1893).

¹⁸⁹ M. Bridel and C. Bourdoul, *Compt. rend.*, 189, 543 (1929).

¹⁹⁰ F. C. Stratton and H. W. von Loesecke, *A Chemical Study of Different Varieties of Bananas during Ripening*. United Fruit Co., Research Dept. Bull. No. 32, 1930.

Their data are given in Tables 14, 15, and 16. In examining these data it will be noticed that the results for reducing sugars in the case of the Gros Michel do not agree with those of Poland *et al.*,¹⁹¹ who found that nonreducing sugars (sucrose) predominated. Strat-

TABLE 14. REDUCING AND NONREDUCING SUGARS IN THE PULP OF BANANAS¹⁰⁰ EXPRESSED AS PERCENTAGE OF FRESH PULP

Variety	Number of days in ripening room ^a							
	0	3	5	7	9	11	14	17
Gros Michel								
Reducing sugars ^b	0.24	2.81	7.24	10.73	12.98	15.31	—	—
Nonreducing sugars ^c	0.62	4.85	6.52	6.12	3.89	2.60	—	—
Total sugars	0.86	7.66	13.76	16.85	16.87	17.91	—	—
Lady Finger								
Reducing sugars ^b	0.99	2.97	6.21	6.19	7.40	8.77	—	—
Nonreducing sugars ^c	1.05	9.41	15.41	13.38	12.53	12.27	—	—
Total sugars	2.04	12.38	21.62	19.57	19.93	21.04	—	—
Lacatan								
Reducing sugars ^b	0.12	0.50	0.84	2.28	5.16	8.15	9.64	—
Nonreducing sugars ^c	0.88	1.50	2.14	2.89	7.50	10.01	10.23	—
Total sugars	1.00	2.00	2.98	5.17	12.66	18.16	19.87	—
Plantain								
Reducing sugars ^b	0.10	0.29	0.54	0.77	2.79	9.78	18.89	21.10
Nonreducing sugars ^c	0.72	0.56	0.48	0.15	1.05	0.00	0.00	0.00
Total sugars	0.82	0.85	1.02	0.92	3.84	9.78	18.89	21.10
Red banana ^d								
Reducing sugars ^b	0.49	2.94	4.80	5.22	4.10	4.20	—	—
Nonreducing sugars ^c	1.08	7.41	13.70	15.55	16.08	16.64	—	—
Total sugars	1.57	10.35	18.50	20.77	20.18	20.84	—	—

^a Last figures in table represent fruit at full-ripe stage.

^b As invert sugar.

^c As sucrose.

^d Unpublished data by J. T. Manion, United Fruit Co., Research Dept., 1933.

ton and von Loesecke did not use the Official Methods of the Association of Official Agricultural Chemists and it is possible that they failed to destroy invertase prior to analysis. It will also be noticed that the varieties show definite characteristics with regard to reducing and nonreducing sugars.

There is a small but definite decrease in total carbohydrates

¹⁹¹ G. L. Poland, J. T. Manion, M. W. Brenner, and P. L. Harris, *Ind. Eng. Chem.*, 30, 340 (1938).

in all varieties during ripening due to the utilization of part of the glucose in respiration. Gore¹⁹² has experimentally compared this carbohydrate loss with an estimated loss calculated from the actual measurements of respiration. The two values were close, but did not

TABLE 15. STARCH IN THE PULP OF BANANAS¹⁹⁰ EXPRESSED AS PERCENTAGE OF FRESH PULP

Variety	Number of days in ripening room ^a							
	0	3	5	7	9	11	14	17
Gros Michel	20.65	12.85	6.00	2.93	1.73	1.21	—	—
Lady Finger	27.16	15.01	7.03	4.13	1.66	2.26	—	—
Lacatan	23.23	22.82	23.02	19.32	12.25	6.63	2.87	—
Plantain	32.20	31.68	30.90	30.48	28.52	20.17	11.69	6.12
Red banana ^b	25.29	14.70	7.44	3.74	4.12	1.18	—	—

^a Last figure in table represents fruit at full-ripe stage.

^b Unpublished data by J. T. Manion, United Fruit Co., Research Dept., 1933.

TABLE 16. TOTAL CARBOHYDRATES IN THE PULP OF BANANAS¹⁹⁰ EXPRESSED AS PERCENTAGE OF FRESH PULP

Variety	Number of days in ripening room ^a							
	0	3	5	7	9	11	14	17
Gros Michel	21.51	20.49	19.76	19.78	18.60	19.12	—	—
Lady Finger	29.20	27.39	28.65	23.70	21.59	23.30	—	—
Lacatan	24.23	24.82	26.00	24.49	24.91	24.79	22.74	—
Plantain	33.02	32.53	31.92	31.40	32.36	29.95	30.58	27.22
Red banana ^b	26.86	25.05	25.94	24.51	24.30	22.02	—	—

^a Last figure in table represents fruit at full-ripe stage.

^b Unpublished data by J. T. Manion, United Fruit Co., Research Dept., 1933.

coincide. It will also be noticed from the data that at times there is an apparent increase in carbohydrate. Such increases have also been found in the results of other workers.¹⁹³⁻¹⁹⁵ It is very likely that these errors are due to failure to destroy invertase prior to analysis.

¹⁹² H. C. Gore, *J. Agr. Research*, 3, 187 (1914).

¹⁹³ L. Ricciardi, *Compt. rend.*, 95, 393 (1882).

¹⁹⁴ E. M. Bailey, *J. Biol. Chem.*, 1, 355 (1906).

¹⁹⁵ R. Reich, *Z. Untersuch. Lebensm.*, 22, 208 (1911).

Other workers such as Geerlings,¹⁹⁶ Corenwinder,¹⁹⁷ Doherty,¹⁹⁸ Smith,¹⁹⁹ Fabriani,²⁰⁰ Hepburn *et al.*,²⁰¹ Webster,²⁰² Barnell,²⁰³ Chace *et al.*,²⁰⁴ and others have determined the composition of the banana. There is considerable lack of agreement between the several investigators, but this is not unexpected in that fruit of several varieties and from different localities was used. In addition, the fruit was subjected to different storage treatments before ripening, and was ripened in various ways.

The identity of the sugars in the banana has been investigated by several workers over a period of many years. Mierau²⁰⁵ as long ago as 1893 showed that the main sugar in ripe bananas was sucrose. In 1908 Geerlings¹⁹⁶ reported that he had isolated sucrose crystals from the fruit. Yoshimura²⁰⁶ stated that outside of sucrose and invert sugar, no other kind is present. Wehmer,²⁰⁷ on the other hand, gives quantitative data for sucrose, glucose, and fructose content of ripe bananas. More recently Widdowson and McCance²⁰⁸ considered the reducing sugars of the fruit as glucose and fructose, since these two sugars when determined separately accounted for all of the reducing sugars. Therefore, the amount of maltose present must be insignificant. Early work by Bailey²⁰⁹ indicated that maltose was not present among the sugars of the fruit. Poland and his co-workers²¹⁰ found maltose to be present in very small amounts in the ripe Gros Michel. Sucrose, glucose, and fructose were also identified. Other sugars tested for, but with

¹⁹⁶ H. C. Prinsen Geerlings, *Intern. Sugar J.*, 10, 372 (1908).

¹⁹⁷ M. B. Corenwinder, *Ann. agron.*, 2, 429 (1876).

¹⁹⁸ W. M. Doherty, *Chem. News*, 66, 187 (1892).

¹⁹⁹ R. Smith, *Agronomia (Cuba)*, 2, 126 (1941).

²⁰⁰ G. Fabriani, *Quaderni Nutriz.*, 6, 199 (1939).

²⁰¹ J. S. Hepburn, N. A. Fegley, K. S. Sohn, J. R. Cox, E. A. Read, and R. F. Wallace, *Am. J. Pharm.*, 105, 547 (1933).

²⁰² P. J. Webster, *Philippine J. Sci.*, 41, 85 (1930).

²⁰³ H. R. Barnell, *Ann. Botany*, 5, 607 (1941).

²⁰⁴ E. M. Chace, L. M. Tolman, and L. S. Munson, *U. S. Dept. Agr. Bull.*, No. 87 (1904).

²⁰⁵ F. Mierau, *Chem.-Ztg.*, 17, 1002, 1021 (1893).

²⁰⁶ K. Yoshimura, *Z. Untersuch. Lebensm.*, 21, 406 (1911).

²⁰⁷ C. Wehmer, *Die Pflanzenstoffe*. Fischer, Jena, 1911.

²⁰⁸ E. M. Widdowson and R. A. McCance, *Biochem. J.*, 29, 151 (1935).

²⁰⁹ E. M. Bailey, *J. Am. Chem. Soc.*, 34, 1706 (1912).

²¹⁰ G. L. Poland, H. W. von Loesecke, M. W. Brenner, J. T. Manion, and P. L. Harris, *Food Research*, 2, 403 (1937).

negative results, were D-mannose, D-, L-, and DL-galactose, D-sorbose, D- and L-mannoheptose, raffinose, melizitose, and rhamnase.

Further work by Poland *et al.*²¹¹ resulted in an evaluation of the sugar changes in bananas during ripening. Glucose, fructose, and sucrose all increased during ripening. Recent work by Barnell²¹² along this same line is in agreement with the results of Poland *et al.*

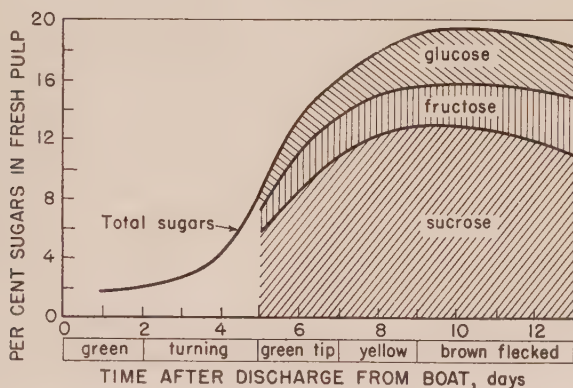


Fig. 23. Sugar content of Gros Michel bananas during ripening.²¹¹

Poland found that the relation of glucose and of fructose to total reducing sugars remained nearly constant. Glucose amounted to approximately 58% and fructose to about 42% of the total reducing sugars, regardless of the stage of ripeness (Table 17).

Barnell's studies of the percentage content of sucrose, fructose, glucose, and glycosidic glucose are of interest because he started his investigations on the fruit immediately after cutting, whereas Poland *et al.* began their work right after the fruit had been unloaded from the ship in the United States. Barnell found that sucrose began to increase during the first day after harvesting while the fruit was still at tropical temperatures awaiting storage. Glucose and fructose were present in very small and approximately equal amounts when received for cold storage, and continued so

²¹¹ G. L. Poland, J. T. Manion, M. W. Brenner, and P. L. Harris, *Ind. Eng. Chem.*, 30, 340 (1938).

²¹² H. R. Barnell, *Ann. Botany*, 5, 217 (1941).

during periods of such storage. When ripened after a short time in cold storage, glucose increased to a higher value than did fructose in $\frac{3}{4}$ full fruit (though this was not observed in heavy $\frac{3}{4}$ full). During later stages of maturity, when visible ripening was taking place, there was evidence of glycoside synthesis.

The starch and total sugars values for the peel were much smaller in magnitude than for the pulp, but they followed similar

TABLE 17. AVERAGE DISTRIBUTION OF SUGARS IN THE BANANA AT VARIOUS STAGES OF RIPENESS (GROS MICHEL FRUIT)²¹¹

Stage of ripeness, color ^a	Fresh pulp, %	Total solids, %	Reducing sugars, %	Total sugars, %
GLUCOSE				
4	2.24	8.61	60.70	19.24
5	3.09	11.84	55.28	19.07
6	3.99	15.83	59.20	21.29
7	4.21	17.47	56.51	21.56
<i>Av.</i>	—	—	57.92	—
FRUCTOSE				
4	1.45	5.58	39.30	12.46
5	2.50	9.58	44.72	15.43
6	2.75	10.91	40.80	14.67
7	3.24	13.44	43.49	16.59
<i>Av.</i>	—	—	42.08	—
SUCROSE				
4	7.95	30.58	—	68.30
5	10.61	40.65	—	65.49
6	12.00	47.62	—	64.03
7	12.08	50.12	—	61.85

^a See color plate opposite page 108.

trends. There was evidence of starch hydrolysis before the fruit was put into cold storage, and while in such storage there was some indication of resynthesis of starch in the peel of both $\frac{3}{4}$ full and heavy $\frac{3}{4}$ full fruit. When ripened, the starch content of the peel fell quickly to low values. Total sugars in the peel showed a steady increase during cold storage, with a more rapid rate of increase toward the end of long storage periods.

Total sugars in the peel continued to increase in percentage amount until the fruit was black and falling from the stem. Barnell states that this continued increase in total sugars was due to the high rate of water loss from the peel at this stage.

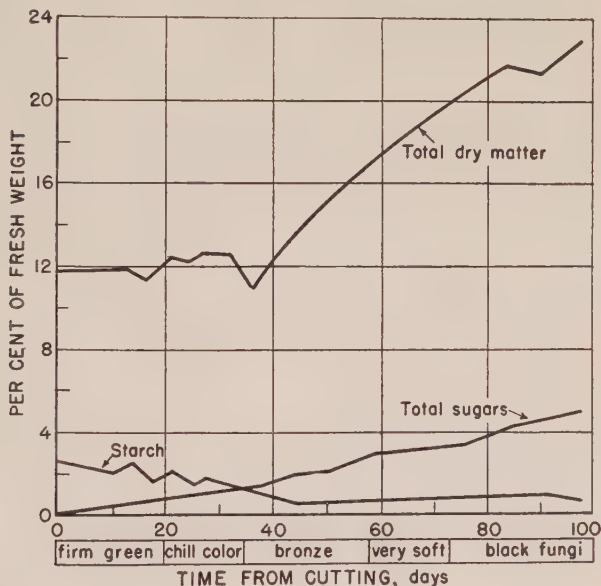


Fig. 24. Dry matter, starch, and total sugars of peel as percentage of fresh weight during storage at 53°F.^{212a}

The starch in bananas has been studied by several investigators. According to Collin,²¹³ the starch grains of the fruit vary in length from 20 to 90 μ and from 12 to 45 μ in width. They are slightly spheroid, but their shape may vary widely. Hanausek²¹⁴ describes banana starch as consisting of single grains and only sporadically as grains in groups. Forms consisting of single grains are classed as:

(1) Flat rounded, egg-shaped or rounded three cornered in form. These are seldom encountered.

^{212a} H. R. Barnell, *Ann. Botany*, 7, 1 (1943).

²¹³ E. Collin, *Ann. fals.*, 8, 280 (1915).

²¹⁴ T. F. Hanausek, *Z. Untersuch. Lebensm.*, 20, 215 (1910).

(2) Bottle-shaped, club-shaped, flask-shaped. These are the chief forms. The nucleus is found mostly on the thick end of the grain; it may sometimes be found on the smaller end.

(3) Curved form, similar to a half moon, sickle-shaped. Also similar to group 2 but bow-shaped.

(4) Straight rods. These are narrow and often of significant length. A long fissure may be noted on some of the grains. This type generally appears in groups of two, seldom in groups of three.

Winton and Winton²¹⁵ state that the starch of green bananas consists of large grains which are much elongated and are sausage-, pear-, or sickle-shaped. They have a length of up to $85\ \mu$; the



Fig. 25. Banana starch.

hilum is usually in the narrow end; the eccentricity is 1:6 to 1:10. Small grains are often in aggregates of two or three. According to Cox,²¹⁶ the starch has a general resemblance to curcuma starch but is somewhat smaller with a grain length of about $30\ \mu$, narrow and somewhat irregular in shape with an eccentric hilum and circular striations.

Hawkins *et al.*²¹⁷ claim that the appearance, size of granules, and paste-forming properties of banana starch resemble potato

²¹⁵ A. L. Winton and K. B. Winton, *The Structure and Composition of Foods*. Vol. I, Wiley, New York, 1932.

²¹⁶ H. E. Cox, *The Chemical Analysis of Foods*. 3rd ed., Churchill, 1946.

²¹⁷ E. G. E. Hawkins, J. K. N. Jones, and G. T. Young, *J. Chem. Soc.*, 1940, 390.

starch. Methylated banana starch had a molecular weight of 200,000, estimated from viscosity data. Its molecular structure is similar to that of rice starch, as indicated by the close resemblance of the course of disaggregation reactions for the methyl derivatives of the two starches. Banana starch has an optical rotation $[\alpha]_D^{20}$ of 152° (c , 0.34) in normal sodium hydroxide.

Lehrman and Kabat²¹⁸ extracted banana starch with petroleum ether until free from extraneous material, and then hydrolyzed the starch with hydrochloric acid, recovering the liberated acids with petroleum ether. This "fat by hydrolysis" consisted of a light yellow semisolid, amounting to about 0.2%, and with an iodine number of 59.4. The fatty acids consisted of a mixture of palmitic, oleic, linoleic (linolic), and linolenic acids, together with a small amount of phytosterol. The investigators state that this is the first time that phytosterol has been found combined with starch. Bates *et al.*²¹⁹ state that banana starch contains 20.5% amylose.

Data have already been presented to show that during commercial ripening of the fruit, the percentage of starch in the pulp decreases (Table 15). Barnell's²²⁰ work dealing with the carbohydrates of bananas stored at 53°F (11.7°C) and then ripened at 68°F . (20°C .) is of interest in this connection. Under such conditions, starch decreases somewhat during the first two or three days from harvesting (this included one day at tropical temperatures and then the period of cooling to 53°F . (11.7°C .) and is then increased slightly. As expected, rapid starch hydrolysis occurred during ripening at 68°F . (20°C .). In fruit undergoing prolonged cold storage treatment, this increased hydrolysis rate began before the fruit was transferred to the ripening room. Total sugars increased slowly during the cold storage period, the high rate of increase when the fruit was transferred to the ripening room coinciding with high starch hydrolysis rate. The accelerated rate of increase in total sugars started in the fruit undergoing prolonged cold storage before it was transferred to the ripening room. Barnell's data are given in Table 18.

²¹⁸ L. Lehrman and E. A. Kabat, *J. Am. Chem. Soc.*, 59, 1050 (1937).

²¹⁹ F. L. Bates, D. French, and R. E. Rundle, *ibid.*, 65, 142 (1943).

²²⁰ H. R. Barnell, *Ann. Botany*, 5, 608 (1941).

TABLE 18. CARBOHYDRATE COMPOSITION OF CHILLED AND OF NORMAL FRUIT AND OF FRUIT RIPENED UNDER TROPICAL CONDITIONS, DURING THE "EATING RIPE" STAGE²⁰ EXPRESSED AS PERCENTAGE OF FRESH PULP. FIGURES IN BRACKETS INDICATE TIME IN DAYS FROM HARVESTING

Condition of fruit	"Boiled"			"Chilled"			"Chilled"		
	Heavy 3/4 full. Ripened at trop. temp.	Heavy 3/4 full. 7 days at 53°F., ripened at 68°F.	Heavy 3/4 full. 14 days at 53°F., ripened at 68°F.	Heavy 3/4 full. 14 days at 53°F., ripened at 68°F.	Standard 3/4 full. 14 days at 53°F., ripened at 68°F.	Standard 3/4 full. 20 days at 53°F., ripened at 68°F.			
Eating quality	Excellent			Excellent					
Starch	[7] 1.56	[16] 3.74	[19] 7.52	[20] 5.25	[25] 5.49				
	[9] 0.654	[18] 1.71	[21] 3.67	[22] 2.89	[27] 2.13				
	[11] 0.357	—	[24] 1.62 ^a	[24] 1.61 ^a	[29] 1.51				
Total sugars	[7] 13.450	[16] 11.515	[19] 6.586	[20] 11.610	[25] 9.770				
	[9] 12.770	[18] 12.630	[21] 10.210	[22] 12.720	[27] 12.235				
	[11] 12.600	—	[24] 11.245 ^a	[24] 12.895 ^a	[29] 12.020				
Sucrose	[7] 3.660	[16] 3.390	[19] 1.888	[20] 3.755	[25] 2.950				
	[9] 1.700	[18] 3.820	[21] 2.421	[22] 3.890	[27] 3.510				
	[11] 0.990	—	[24] 2.356 ^a	[24] 2.220 ^a	[29] 2.970				
Glycosidic glucose	[7] 0.344	[16] 0.347	[19] 0.241	[20] 0.307	[25] 0.282				
	[9] 0.227	[18] 0.232	[21] 0.630	[22] 0.208	[27] 0.213				
	[11] 0.209	—	[24] 0.656 ^a	[24] 0.235 ^a	[29] 0.201				

^a Values thus marked are for fruit which would be judged by eye to be slightly overripe.

E. Changes in Pectin and Protopectin during Ripening

Stratton and von Loesecke²²¹ have shown that pectin increases and protopectin decreases during ripening (Tables 19 and 20). It is assumed that protopectin is converted to pectin and

TABLE 19. PECTIN (AS CALCIUM PECTATE) IN THE PULP OF BANANAS DURING RIPENING²²¹ EXPRESSED AS PERCENTAGE OF FRESH PULP

Variety	Days in ripening room ^a							
	0	3	5	7	9	11	14	17
Gros Michel	—	0.27	0.36	0.34	0.37	0.40	—	—
Lady Finger	0.21	0.48	0.52	0.57	0.58	0.68	—	—
Lacatan	Trace	Trace	0.13	0.14	0.31	0.41	0.46	—
Plantain	0.12	0.14	0.14	0.12	0.19	0.24	0.43	0.33
Red banana ^b	0.04	0.20	0.55	0.77	0.62	0.63	—	—

^a Last figures in table represent fruit at full-ripe stage.

^b Unpublished data by J. T. Manion, United Fruit Co., Research Dept., 1933.

TABLE 20. PROTOPECTIN (AS CALCIUM PECTATE) IN THE PULP OF BANANAS DURING RIPENING²²¹ EXPRESSED AS PERCENTAGE OF FRESH PULP

Variety	Days in ripening room ^a							
	0	3	5	7	9	11	14	17
Gros Michel	0.53	0.56	0.31	0.34	0.21	0.22	—	—
Lady Finger	0.50	0.76	0.27	0.29	0.31	0.35	—	—
Lacatan	0.59	0.78	1.15	0.99	0.40	0.35	0.34	—
Plantain	0.48	0.47	0.96	0.79	1.03	0.75	0.37	0.57
Red banana ^b	0.87	1.14	0.52	0.42	0.43	0.48	—	—

^a Last figures in table represent fruit at full-ripe stage.

^b Unpublished data by J. T. Manion, United Fruit Co., Research Dept., 1933.

finally into pectic acid. Conrad²²² has reported that during the ripening of fruits pectin increases at the expense of protopectin. He further showed that concurrently with the development of soluble pectin there is liberated an unidentified furfural-yielding substance, soluble in 70% alcohol, which increases progressively

²²¹ F. C. Stratton and H. W. von Loesecke, *A Chemical Study of Different Varieties of Bananas During Ripening*. United Fruit Co., Research Dept. Bull. No. 32, 1930.

²²² C. M. Conrad, *Plant Physiol.*, 5, 93 (1930).

with the pectin. Fluctuations in protopectin values observed during the ripening of some varieties of bananas are probably due to irregular formation of protopectin from the pectic substances of the middle lamella.²²¹ Such a phenomenon has been noted by Haller²²³ in his studies with apples.

F. Changes in Cellulosic Constituents during Ripening

These constituents, which include cellulose, hemicellulose, and lignin, are generally reported under "crude fiber." Mangold²²⁴ has defined this term as "the sum of all organic components of the plant cell membrane and supporting structure which in chemical analysis of plant foodstuffs remain after removal of crude protein, crude fat, and nitrogen-free extractives." Jacquot²²⁵ recently pointed out that the determination of "crude fiber" is meaningless from a physiological standpoint.

With the growing appreciation of the importance of fibrous food materials in the diet, nutritionists have recently investigated the cellulose, hemicellulose, and lignin contents of foods. Hummel and co-workers,²²⁶ using the method of Williams and Olmsted²²⁷ for determining these three constituents, found the crude fiber of bananas to consist of 60% lignin, 25% cellulose, and 15% hemicellulose. The ripe pulp itself contained 0.50% lignin, 0.21% cellulose, and 0.12% hemicellulose. These figures agree closely with those obtained by McMaster²²⁸ (Table 21).

In a recent paper, Barnell²²⁹ has demonstrated the importance of hemicelluloses in the metabolism of the banana. No attempt was made to isolate or to identify the individual hemicelluloses. It should also be noted that Barnell classed as hemicelluloses the material obtained by the difference: (total alcohol-insoluble residue percentage of the fresh weight) minus (starch plus cellulose plus pectin percentages). Since this technique differed from that used

²²³ M. H. Haller, *J. Agr. Research*, 32, 739 (1929).

²²⁴ E. Mangold, *Nutrition Abstracts & Revs.*, 3, 647 (1934).

²²⁵ R. Jacquot, *Chimie & industrie*, 55, 424 (1946).

²²⁶ F. C. Hummel, M. L. Shepard, and I. C. Macy, *J. Am. Dietet. Assoc.*, 16, 199 (1940).

²²⁷ R. D. Williams and W. H. Olmsted, *J. Biol. Chem.*, 108, 653 (1935).

²²⁸ D. R. McMaster, *unpublished data*, Research Dept., United Fruit Co.

²²⁹ H. R. Barnell, *Ann. Botany*, 7, 297 (1943).

by Hummel *et al.* and McMaster, Barnell's figures will not check with those obtained by these workers.

Hemicelluloses in the pulp were reported by Barnell to be present in quantities of from 8 to 10% in the green fruit, and they decreased rapidly to about 1 to 2% during ripening. McMaster

TABLE 21. INDIGESTIBLE RESIDUE OF BANANAS²²⁸

Color No. ^a	Lignin, %	Cellulose, %	Hemicellulose, %	Total fiber, %
BASED ON THE FRESH PULP				
1	0.49	0.15	0.21	0.85
2	0.57	0.14	0.17	0.88
3	0.54	0.13	0.16	0.83
4	0.55	0.13	0.14	0.82
5	0.54	0.16	0.14	0.84
6	0.50	0.16	0.13	0.79
7	0.46	0.19	0.12	0.78
AS PERCENTAGE OF TOTAL INDIGESTIBLE RESIDUE				
1	58	18	24	—
2	65	16	19	—
3	65	16	19	—
4	67	16	17	—
5	64	19	17	—
6	63	20	17	—
7	60	25	15	—

^a See color plate opposite page 108.

also showed a decrease in hemicellulose during ripening. As previously pointed out, this period is one of intense metabolic activity characterized by active hydrolysis. The disappearance of hemicellulose at this time is probably due to hydrolysis, and part of the sugar and acid accumulation at this period may be ascribed to the hemicelluloses.²²⁹

Barnell believes that hemicelluloses in the fruit pulp must be considered a labile reserve carbohydrate. Upon hydrolysis, they give rise to substances that may serve as a substrate for the respiration process. Such substances may give rise to hexoses, pentoses, and uronic acids. It is postulated that uronic acids, on partial oxidation, give rise to such dibasic acids as malic or succinic. Unpublished data by Barnell showed that the time hemicellulose decreased,

TABLE 22. COMPOSITION (PERCENTAGE OF FRESH WEIGHT) OF THE PULP OF STANDARD 3/4 FULL FRUIT DURING STORAGE AT 53°F. (11.7°C.) AND RIPENING AT 68°F. (20°C.)²²⁹

Days from harvest	Temp., °F.	Total alc. sol. residue	Starch	Cellulose (insol. in N/75 HCl)	Pectin (as calcium pectate)	Hemicellulose
0	80-85	27.22	16.78	2.64	0.00	7.80
20 hrs.	80-85	27.13	15.96	2.62	0.06	8.49
26 hrs.	53	27.68	15.91	2.78	0.04	8.95
3	53	28.18	15.66	2.13	0.09	10.30
6	53	26.96	16.45	2.40	0.06	8.05
10	53	27.04	16.99	2.53	0.09	7.43
14	53	26.36	16.56	2.18	0.10	7.52
17	53	25.25	16.26	2.23	0.11	6.65
19	53	24.48	14.53	2.85	0.58	6.52
21	68	22.68	13.34	2.42	0.02	6.90
23	68	16.60	9.55	2.25	0.11	4.69
25	68	10.29	5.49	2.06	0.41	2.33
27	68	5.77	2.13	2.14	0.04	1.46
29	68	4.85	1.51	1.49	0.10	1.75
31	68	4.04	1.08	2.24	0.00	0.72
33	68	3.36	0.70	1.67	0.00	0.99
16	68	26.07	16.47	3.39	0.00	6.21
18	68	19.12	12.25	1.93	0.00	4.94
20	68	9.76	5.25	1.87	0.07	2.57
22	68	6.80	2.89	1.68	0.04	2.19
24	68	4.82	1.61	1.58	0.03	1.60
26	68	3.84	0.88	1.38	0.01	1.57
28	68	3.70	0.85	1.55	0.02	1.28
<i>Significant difference</i>		—	0.67	0.37	—	0.78

titratable acidity rose and the pH fell. It is believed that such changes are brought about by catabolism of hemicelluloses.

Hemicellulose hydrolysis is delayed to about the same extent as starch hydrolysis in bananas subjected to a temperature of 53°F. (11.7°C.). Once the rapid hydrolysis has started, however, hemicellulose disappears at the same rate, whatever the previous history of the fruit may have been.

There is probably some conversion of starch to hemicelluloses in the pulp, and then hemicelluloses back to starch during the early stages of the cold storage of bananas (Barnell²²⁹).

From a practical standpoint, the hemicellulose percentage appears to be of significance as a quality factor affecting the tex-

TABLE 23. COMPOSITION (PERCENTAGE OF FRESH WEIGHT) OF THE PEEL OF STANDARD 3/4 FULL FRUIT DURING STORAGE AT 53°F. (11.7°C.) AND RIPENING AT 68°F. (20°C.)²²⁰

Days from harvest	Temp., °F.	Total alc. sol: residue	Starch	Cellulose (insol. in N/75 HCl)	Pectin (as calcium pectate)	Hemi-cellulose
0	80-85	9.69	3.20	3.04	0.37	3.08
20 hrs.	80-85	9.84	3.18	3.13	0.30	3.23
26 hrs.	53	9.77	2.94	3.14	0.40	3.29
3	53	9.75	2.90	3.12	0.22	3.51
6	53	9.83	2.86	3.49	0.24	3.24
10	53	9.83	2.88	3.74	0.20	3.01
14	53	9.53	2.96	3.86	0.91	1.80
17	53	9.55	2.36	3.95	0.80	2.44
19	53	9.95	2.33	4.04	0.30	3.28
21	68	9.86	2.28	3.82	0.56	3.20
23	68	9.74	2.12	4.64	0.60	2.38
25	68	8.93	1.12	4.19	0.61	3.01
27	68	9.52	0.51	5.20	0.57	3.24
29	68	9.90	0.50	5.42	0.60	3.38
31	68	10.32	0.44	5.70	0.50	3.68
33	68	10.59	0.38	5.06	0.39	4.76
16	68	9.60	2.40	3.20	0.35	3.65
18	68	9.09	2.23	3.19	0.42	3.25
20	68	8.08	0.84	4.02	0.40	2.82
22	68	7.85	0.50	4.06	0.36	2.93
24	68	8.24	0.46	4.47	0.35	2.96
26	68	8.78	0.37	5.05	0.37	2.99
28	68	9.39	0.40	4.99	0.39	3.61
<i>Significant difference</i>		—	0.21	0.48	—	0.37

ture of the pulp. Thus, fruit stored continuously at 53°F. (11.7°C.) eventually "ripens" to a condition where the starch and sugar percentages correspond fairly closely with those recognized as characteristic of eating-ripe fruit; but the percentage of hemicellulose is low, and the fruit pulp is of a watery consistency and has an astringent flavor.

Barnell²²⁹ found that the peel of the fruit contained much less hemicellulose than the pulp, and the decrease in absolute amount of hemicellulose during ripening was relatively small. No appreciable differences could be found between fruits stored for long and short periods. Some of Barnell's data are given in Tables 22 and 23 above.

G. Changes in Acidity during Ripening

During ripening, titratable acidity of the pulp increases to a peak in the case of some varieties, and then declines. Ricciardi,²³⁰ in a paper published in 1882, stated that the organic acids disappeared during ripening. From the data of Stratton and von Loesecke²³¹ it would appear that, for the Plantain, increase in acidity continues during the greater part of the ripening period, and the ripe fruit has a definite acid taste (Table 24). In general,

TABLE 24. TITRATABLE ACIDITY OF BANANA PULP²³¹ EXPRESSED AS CUBIC CENTIMETERS OF NORMAL SODIUM HYDROXIDE TO NEUTRALIZE 100 GRAMS OF PULP

Variety	Days in ripening room ^a							
	0	3	5	7	9	11	14	17
Gros Michel	2.96	3.56	4.95	4.46	4.08	3.66	—	—
Lady finger	2.71	5.93	5.87	4.27	4.00	4.07	—	—
Lacatan	2.60	2.13	3.40	3.27	4.71	4.06	4.20	—
Plantain	2.67	2.20	2.53	2.60	4.39	6.20	9.00	7.20
Red banana ^b	3.04	4.85	4.60	4.80	4.05	5.60	—	—

^a Last figure in table represents fruit at full-ripe stage.

^b Unpublished data by J. T. Manion, United Fruit Co., Research Dept., 1933.

the rate of acid production and its later decrease follows the same trend as starch hydrolysis, *i.e.*, when hydrolysis is proceeding most rapidly, the acidity is increasing most markedly, and as the rate of hydrolysis is reduced, acidity becomes progressively less. But it is not probable that the amount of acid itself is sufficient to perform hydrolysis of the comparatively large quantities of starch present in the pulp.

Barnell²³² notes the association of changing acidity during ripening with color, rising acidity values being accompanied by yellowing but with a time delay in the peel of about two days compared with the pulp. He suggests that acidity changes may be connected with changes in the mechanism of the respiratory process.

²³⁰ L. Ricciardi, *Compt. rend.*, 95, 393 (1882).

²³¹ F. C. Stratton and H. W. von Loesecke, *A Chemical Study of Different Varieties of Bananas during Ripening*. United Fruit Co., Research Dept. Bull. No. 32, 1930.

²³² H. R. Barnell, *Ann. Botany*, 5, 217 (1941).

In a later paper Barnell²³³ showed that in general the pulp was slightly more acid than the peel during the ripening period. However, there was a downward trend in the acidity of both peel and pulp when bananas were placed in cold storage 53°F. (11.7°C.); but on removal to the ripening room increased values were obtained for both long- and short-storage fruit, the values of the pulp increasing more rapidly than those of the peel in each

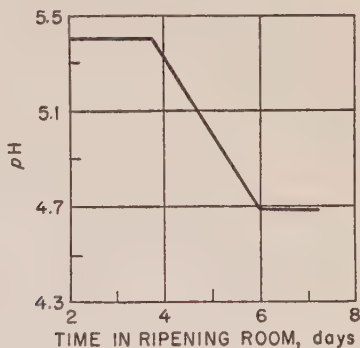


Fig. 26. pH change in Gros Michel bananas during ripening at 19°C.

instance. Barnell believes that this indicates that ripening takes place from the pulp outward. In the pulp, and to a lesser extent in the peel, titratable acidity attained higher values during ripening in long-storage fruit than in short-storage fruit.

The pH of the fruit varies from 5.02 to 5.6 in green bananas, to from 4.20 to 4.75 in the ripe fruit.²³⁴⁻²³⁷ This comparatively high pH would seem to preclude any safe method of canning bananas, except by retort processing, or by the addition of an acid to increase the hydrogen ion concentration.

The nature of the acid in the fruit has been the subject of considerable research. As early as 1876 a paper by Corenwinder²³⁸ ascribed the acidity as due to malic acid. Wehmer,²³⁹ quoting

²³³ H. R. Barnell, *ibid.*, 5, 608 (1941).

²³⁴ P. L. Harris and G. L. Poland, *Food Research*, 2, 135 (1937).

²³⁵ *Banana Ripening Manual*. United Fruit Company, New York, 1942.

²³⁶ N. C. Thornton, *Contrib. Boyce Thompson Inst.*, 13, 201 (1943).

²³⁷ K. Wülfert, *Biochem. Z.*, 302, 232 (1939).

²³⁸ M. B. Corenwinder, *Ann. agron.*, 2, 429 (1876).

²³⁹ C. Wehmer, *Die Pflanzenstoffe*. Fischer, Jena, 1911.

earlier reports, indicated that malic acid, unaccompanied by oxalic, acetic, or citric acids, was present in the green fruit. Bigelow and Dunbar²⁴⁰ generalized that bananas probably contained only malic acid. Hartmann and Hillig²⁴¹ reported the presence of citric as well as malic acid. Harris and Poland,²³⁴ on the other hand, were

TABLE 25. PERCENTAGE OF NONVOLATILE ACIDS IN BANANAS

Malic acid	Citric acid	Observer
0.053-0.373	—	Harris and Poland ²³⁴
0.37-0.50	0.15-0.32	Hartmann and Hillig ²⁴¹
0.26-0.19	—	Wehmer ²³⁹
0.24 ^a	—	Nelson ^{241a}

^a Ripe fruit.

unable to find citric acid. Raymond and Jojo²⁴² found traces of oxalic acid in the plantain. Kohman^{242a} reported oxalic acid to be present in the amount of 0.0064%. The fruit was probably Gros Michel, although Kohman does not state the variety. Niethammer²⁴³ claims to have "sublimed" a small amount of oxalic acid from ripe bananas (presumably *M. sapientum*), while malic acid was obtained from the unripe fruit. Fonseca²⁴⁴ found citric, malic, boric, tartaric, acetic, and butyric acids in two varieties of Brazilian bananas. Niethammer found tartaric acid in the ripe fruit he investigated. Hartmann and Hillig, on the other hand, could find no measurable quantities of tartaric acid in the fruit they examined.

From the data available, it would appear that the principal nonvolatile acid of the fruit is malic. According to Harris and Poland,²³⁴ this acid occurs as free acid in the ripe fruit. During ripening, the *l*-malic acid reaches a peak, then gradually decreases as the banana matures. Titratable acidity is a good measure of *l*-malic acid at any time after the peel is more yellow than green.

²⁴⁰ W. D. Bigelow and P. B. Dunbar, *Ind. Eng. Chem.*, 9, 762 (1917).

²⁴¹ B. G. Hartmann and F. Hillig, *J. Assoc. Off. Agr. Chem.*, 17, 522 (1934).

^{241a} E. K. Nelson, *Am. Med.*, 34, 812 (1928).

²⁴² W. D. Raymond and W. J. Jojo, *East African Agr. J. Kenya Tanganyika Uganda Zanzibar*, 17, 105 (1940).

^{242a} E. F. Kohman, *J. Nutrition*, 18, 233 (1939).

²⁴³ A. Niethammer, *Z. Untersuch. Lebensm.*, 59, 501 (1930).

²⁴⁴ C. Fonseca, *Rev. alimentar Rio de Janeiro*, 5, No. 37, 29 (1941).

In a lengthy paper, Brunner and Chuard²⁴⁵ claim to have found glycosuccinic acid (as such) in unripe bananas, but this acid almost entirely disappears in the ripe fruit. Glycosuccinic acid, according to these investigators, is a combination of one molecule of glucose and two molecules of succinic acid: $C_6H_{10}O_4(HOOC \cdot CH_2 \cdot CH_2 \cdot COOH)_2$. The acid was identified through its lead salt. Apparently this substance can absorb iodine, for Brunner and Chuard speak of an iodine-absorbing material in plant juice. If the iodine-absorbing plant juice is heated for a short time with sodium hydroxide or dilute sulfuric acid, it will no longer absorb iodine.* These workers believe that glycosuccinic acid is an assimilation product of plants.

H. Changes in Tannins during Ripening

In his early work on bananas, Buignet²⁴⁶ recognized that changes took place in the tannin content of the fruit, and that unripe fruit contained considerable tannin which diminished as the fruit ripened. Ricciardi's²⁴⁷ results agree with those of Buignet. Yoshimura,²⁴⁸ on the other hand, stated that tannin remained unchanged during the ripening process. He probably arrived at this conclusion because of the fact that he estimated tannins by precipitation with copper acetate, and his figures do show that this type of tannin remains constant during ripening. Undoubtedly there is more than one type of tannin in the fruit, although there are no comprehensive published data to substantiate this belief. Onslow²⁴⁹ reported that the peel of the fruit contained substances with the catechol grouping, but that these are practically absent in the flesh. However, Scurti and Pavarino²⁵⁰ imply that there is more than one type of tannin, for they state that during normal ripening the soluble tannins gradually decrease. In bananas kept at 32°F. (0°C.), tannins are unaltered but diffuse in the tissues of the peel and are oxidized by atmospheric oxygen.

* It is not impossible that this was ascorbic acid, unknown at that time.

²⁴⁵ H. Brunner and E. Chuard, *Ber.*, 19, 595 (1886).

²⁴⁶ M. H. Buignet, *Ann. chim. phys.*, 61, 233 (1861).

²⁴⁷ L. Ricciardi, *Compt. rend.*, 95, 393 (1882).

²⁴⁸ K. Yoshimura, *Z. Untersuch. Lebensm.*, 21, 406 (1911).

²⁴⁹ M. W. Onslow, *Biochem. J.*, 14, 541 (1920).

²⁵⁰ F. Scurti and G. L. Pavarino, *Ann. sper. agrar. Rome*, 15, 91 (1934).

Harris and Poland²⁵¹ recognize more than one tannin as being present when they state that the total amount of tannins remains practically constant during ripening, the change merely being in their state, or form of existence. In a later paper²⁵² these same workers point out that free tannin decreases as the fruit ripens because the tannins are slowly bound in an insoluble, supposedly inert, "vegetable tannate."

Based on their histochemical work, Sastri and Row²⁵³ believe that ripening of the fruit is controlled by the presence or disappearance of tannins.

Barnell and Barnell²⁵⁴ recognize two kinds of tannin-containing elements in green bananas: (a) latex vessels present in both pulp and peel, and (b) small scattered parenchymatous cells in the outer and middle regions of the peel. The tannin is in solution and apparently evenly distributed within the vessels and cells. As the fruit ripens, the nature of the contents of the latex vessels changes, a condition earlier recognized by Slocum.²⁵⁵ The tannins in solution appear to some extent in the parenchymatous cells, particularly in those adjacent to the latex vessels of the peel. The tannin content of the small scattered cells of the peel appears to undergo little or no change. These investigators believe that loss of astringency is probably associated with the changes in the tannin content of the laticiferous vessels.

A feature of the unripe fruit is its strongly astringent taste, and this taste does not entirely disappear even in the ripened fruit. One means of assessing the quality of ripened fruit may therefore be based on the amount of "astringent tannins" present. There is some question as to whether or not degrees of astringency determined organoleptically can be correlated with the quantity of tannin as estimated by the usual methods, such as comparing colors obtained with iron salts. In fact this was pointed out as far back

²⁵¹ P. L. Harris and G. L. Poland, *Food Research*, 2, 135 (1937).

²⁵² P. L. Harris and G. L. Poland, *J. Lab. Clin. Med.*, 24, 580 (1939).

²⁵³ B. N. Sastri and G. R. Row, *Proc. Indian Acad. Sci.*, B1, 318 (1934).

²⁵⁴ H. R. Barnell and E. Barnell, *Ann. Botany*, 9, 77 (1945).

²⁵⁵ A. H. Slocum, *Effect of Low Temperature upon Cell Structure*, United Fruit Co., Research Dept., Bull. No. 48, 1933.

²⁵⁶ Cullen, *A Treatise of the Materia Medica*. Vol. II, Edinburgh, 1789, pp. 1-52.

as 1789 by Cullen²⁵⁶ who held that there was no relationship between the amount of tannin present in a material and its astringency. Later work by Phillips²⁵⁷ and by Crede²⁵⁸ have supported this view.

Barnell and Barnell²⁵⁴ studied the changes in so-called "active tannin" of bananas during ripening by the use of a method based on the observations of Brown and Morris²⁵⁹ that diastase is precipitated or otherwise inactivated in the presence of tannin. The method, of course, indicates only that type of tannin capable of inhibiting diastase, and the results are expressed in "standard units" which assess the inhibitory activity of the solutions tested, and, by assumption, their astringency.

Table 26 gives data relative to the changes in active tannin in fruit ripened at 68°F. (20°C.). Referring to this table, all estimations shown in the columns headed Series 1 and Series 2 were made with the "standard" method, which is not sensitive enough for the small quantities noted in the pulps and peels of ripe and over-ripe bananas. In Series 3 the values from the 9th day onward were obtained by the "modified" method. Significant differences for the last five values of Series 3 were 0.30, 0.28 (Barnell and Barnell²⁵⁴). It will be seen from the data that, in general, after harvesting there was a delay before the concentration of active tannin began to fall. The decrease started shortly before the fruit attained the "sprung" condition and began to change color. Of further interest, is the relationship between active tannin content of the fruit and its eating quality (Table 27).

There is probably a relationship between the changes in the amount of tannin present and changes in other metabolites. Scurti and Pavarino,²⁶⁰ for instance, have suggested a relation between the appearance of aldehyde and the disappearance of tannin. Barnell and Barnell²⁵⁴ point out that acetaldehyde is probably a product of the respiration process of the fruit under conditions of low oxygen pressure and it is significant that the tannin content of the pulp falls rapidly during the stage in which the internal oxygen con-

²⁵⁷ R. C. Phillips, *J. Am. Leather Chem. Assoc.*, 17, 565 (1922).

²⁵⁸ E. Crede, *ibid.*, 20, 573 (1925).

²⁵⁹ H. T. Brown and G. H. Morris, *J. Chem. Soc.*, 63, 604 (1893).

²⁶⁰ F. Scurti and G. L. Pavarino, *Ann. sper. agrar. Rome*, 15, 91 (1934).

TABLE 26. CHANGES IN THE AMOUNT OF "ACTIVE" TANNIN IN THE PULP AND PEEL OF HEAVY 3/4 FULL BANANAS DURING RIPENING^a EXPRESSED AS STANDARD UNITS PER 100 GRAMS OF TISSUE²⁶⁴

Days	Series 1			Series 2			Series 3		
	Fruit condition	Pulp	Peel	Fruit condition	Pulp	Peel	Fruit condition	Pulp	Peel
0	Green	7.36	40.5	Green	—	—	Green	—	—
1	Green	8.01	34.0	Green	7.47	30.9	Green	—	—
2	Green	7.57	28.3	Green	6.75	27.2	Green	—	—
3	Green	4.30	25.4	Green	7.02	18.1	Green	11.1	30.2
4	Green	5.02	25.9	Green	8.51	17.9	Green	—	—
5	Coloring	4.30	16.5	Coloring	3.50	23.9	Coloring	12.0	30.3
6	Coloring	3.87	18.1	Eating-ripe	4.35	11.9	Coloring	—	—
7	Coloring	1.95	11.2	Eating-ripe	2.57	4.83	Eating-ripe	3.02	4.01
8	Eating-ripe	2.84	4.58	Overripe	1.43	2.20	Eating-ripe	—	—
9	Eating-ripe	1.99	4.72	Overripe	1.13	1.89	Eating-ripe	1.52	2.02
10	Overripe	2.00	4.51	Overripe	—	—	Overripe	1.26	2.17
11	Overripe	1.32	3.51	Overripe	1.07	2.25	Overripe	1.37	2.52
12	—	—	—	—	—	—	Overripe	1.35	2.17
13	—	—	—	—	—	—	Overripe	1.38	2.97
Sig. diff. ($p = 0.05$)				—	1.66	3.68	—	2.92	8.52

^a At tropical temperature.

centration is falling.^{261,262} The oxygen value reaches a minimum at the "sprung" condition and then usually recovers to some extent, but, as indicated in Table 26, the tannin content continues to fall until the eating-ripe stage; after this, an approximately steady concentration is maintained.

TABLE 27. EATING QUALITY AND "ACTIVE" TANNIN CONTENT OF BANANA PULP²⁵⁴

Description	Days from harvesting	Tannin, units per 100 grams of pulp	Eating quality
<i>Healthy.</i> Standard 3/4 full. Ripened at tropical temperatures. "Sprung" on 11th day, coalescing brown spots on 18th day.	14 15 16 18	0.94 0.97 1.07 0.99	Good
<i>Healthy.</i> Standard 3/4 full. Stored at 53°F. (11.7°C.) throughout experiment.	52 43 54	2.17 2.14 2.28	

I. Phytin

The report of Bagaoisan²⁶³ that the bananas examined by him contained phytin may have nutritional implications. Phytin is the calcium magnesium salt of phytic acid (inositol hexaphosphoric acid). Phytic acid itself has been shown to interfere with the absorption of calcium, either by precipitation or by conversion into a form which is not readily absorbed from the intestine.²⁶⁴ Re-

TABLE 28. PHYTIN CONTENT OF BANANAS²⁶³ BASED ON WEIGHT OF OVEN-DRIED SAMPLE

Variety of fruit, <i>M. sapientum</i>	Phytin, %
Lacatan (ripe)	5.11
Sueveoleus (Bungulan)	0.41
Grandis Teodoro	0.67

²⁶¹ C. W. Wardlaw, *Imp. Coll. Trop. Agr. Trinidad, Mem. Low Temp. Res. Sta.*, No. 15, 1940.

²⁶² C. W. Wardlaw, E. R. Leonard, and H. R. Barnell, *Ann. Botany*, 3, 845 (1939).

²⁶³ C. L. Bagaoisan, *Philippine Agr.*, 21, 53 (1932).

²⁶⁴ Anon., *Nutrition Rev.*, 3, 61 (1945).

searches by Harrison and Mellanby²⁶⁵ have shown, however, that phytin does not have rachitogenic properties; phytic acid is strongly rachitogenic. There are no published data available to indicate conclusively whether phytin is present in the banana entirely as such, or whether phytic acid is also present.

J. Changes in Protein during Ripening

Stratton and von Loesecke²⁶⁶ have shown that there is no significant change in the protein content of bananas during ripening. Such differences as were noticed are probably due to experimental error. Recalculation of Gore's data²⁶⁷ to a dry basis also indicate no significant differences between the protein content of ripe and unripe pulp.

TABLE 29. NITROGEN FRACTIONS OF THE ALBUMIN-GLOBULIN BANANA PROTEIN²⁶⁸

Fraction	Percentage	Fraction	Percentage
Amide N	10.13	Arginine	11.08
Humins N	2.92	Histidine	0.39
Monamino N	64.37	Lysine	3.26
Nonamino N	7.65	Total	99.80

The nature of banana protein has not been thoroughly investigated. Perhaps the most comprehensive study was made by Eddy.²⁶⁸ Several tons of ripe banana pulp were extracted with 10% sodium chloride at pH 4.8 to obtain the albumin and globulin fraction. The extract thus obtained was heated to yield a light tan colored precipitate. When washed free from chlorides and dried the yield amounted to 0.2801 gram from 500 grams of pulp, and with an average nitrogen content of 14.22%. The amino acid dis-

²⁶⁵ D. C. Harrison and E. Mellanby, *Biochem. J.*, **33**, 1660 (1939).

²⁶⁶ F. C. Stratton and H. W. von Loesecke, *A Chemical Study of Different Varieties of Bananas during Ripening*. United Fruit Co., Research Dept. Bull. No. 32, 1930.

²⁶⁷ H. C. Gore, *J. Agr. Research*, **3**, 187 (1914).

²⁶⁸ W. H. Eddy, *Nutritive Value of the Banana*. Teachers College, Columbia Univ., New York, 1933.

tribution in this fraction is given in Table 29. The only essential amino acid indicated is lysine. At the time the analysis was carried out, present refined methods of amino acid determination were unknown. In the light of our newer knowledge of estimating amino acids, further work on the nature of banana protein should be of value.

Besides the albumin and globulin in banana protein, Eddy's data indicate the possible presence of glutelin, and proteoses and prolamins, as well as other unidentified fractions (Table 30). It is

TABLE 30. DISTRIBUTION OF BANANA NITROGEN IN 500 GRAMS OF FRESH PULP²⁶⁸

Fraction	Nitrogen, g.	Kind of protein
1. Theoretical (1.3% protein, N $\times$ 6.25)	1.0400	—
2. NaCl extract	0.0398	Albumin and globulin
3. NaCl filtrate	0.0084	Albumin and globulin (?)
4. Acetic acid precipitate of alkaline alcohol extract	0.2883	Glutelin
5. Filtrate from 4	0.2249	Proteoses and prolamins (?)
6. N absorbed on kieselguhr used in filtering NaCl extract	0.2624	Undetermined
7. Refuse pulp from all extractions	0.2638	Undetermined
<i>Total nitrogen recovered</i>	<i>1.0876</i>	

possible that fraction 6 given in the table could be albumin and globulin, but since the technique used is not described it is impossible to decide this point. Although the nitrogen recovered checks rather closely with the theoretical nitrogen, only 31% of the nitrogen was identified as defined protein. According to Eddy,²⁶⁸ a study of some of the fractions indicated that at least a part of the nitrogen was tannin nitrogen in insoluble combination with the protein.

Piness and his co-workers²⁶⁹ studied comparative methods of protein extraction for use in their clinical studies (Table 31).

More recently Engelfried²⁷⁰ has investigated the relationship between the allergic activity and the protein fractions of certain

²⁶⁸ G. Piness, H. Miller, and G. A. Alles, *J. Am. Med. Assoc.*, 83, 608 (1924).

²⁷⁰ J. J. Engelfried, *J. Allergy*, 11, 569 (1940).

foods. He extracted the protein from bananas with 2% sodium chloride, filtered the mass, and then extracted the residue with 2% sodium hydroxide. The filtrates from the sodium chloride and

TABLE 31. COMPARATIVE METHODS OF PROTEIN EXTRACTION FROM BANANAS²⁶⁹

Extraction medium	Total N, mg./cc.	Diff. between total and nonprotein N, mg./cc.
1% NaCl	0.79	0.51
5% NaCl	0.78	0.58
10% NaCl	0.79	0.51
0.5% NaOH	0.92	0.64
0.5% NaOH + 5% NaCl	0.88	0.62
Coca's solution ^a	0.78	0.56
10% alcohol	0.80	0.80
70% alcohol	0.60	0.60
95% alcohol	0.58	0.26

^a A dilute sodium bicarbonate-phenol solution.

sodium hydroxide extracts were combined and an excess of ammonium sulfate was added. The precipitated proteins were removed by filtration and dialyzed in a collodion membrane. The nitrogen content of the protein fractions is given in Table 32. Of particular

TABLE 32. NITROGEN CONTENT OF PROTEIN FRACTIONS OF BANANAS²⁷⁰

Protein fraction	Total N, milligram per cent	Total N after ultrafiltration, milligram per cent	
		Extract retained in collodion sac	Filtrate passed through collodion sac
Water soluble	15.1	28.3	4.7
NaCl soluble	4.4	4.5	2.6
NaOH soluble	77.8	—	—

interest is the fact that the allergens from bananas can be removed from a protein emulsion by ultrafiltration through a collodion membrane.

K. Changes in Fatty Material during Ripening

Bananas exhibit no characteristic change in fat (as represented by an ethyl ether extract) during ripening.²⁷¹ Little is known relative to the physical and chemical properties of the fatty material of the fruit. Moss²⁷² extracted dried bananas with ethyl ether, removed the ether by distillation, and then extracted the residue with petroleum ether. He obtained two grams of a rather dark brown oil from 30 (dried?) bananas. Moss called this material "banana oil," an unfortunate choice of name because the term "banana oil" is generally associated with a volatile oil. The fatty material had the following characteristics:

Refractive index	1.4648
Iodine number	82
Unsaponifiable matter, %	14.4
Sterol (precipitated by digitonin)	30.6% of the unsaponifiable matter
Mean molecular weight of the fatty acids	286
Iodine number of fatty acids	90

Moss believes the sterol was probably sitosterol, but there was insufficient material available to undertake a detailed analysis.

L. Change in Ash during Ripening

There are apparently no marked differences in the total ash during ripening, or between different varieties.²⁷¹ Beside the more common constituents of the ash as pointed out in Table 33, the fruit has been reported to contain zinc, iodine, copper, and aluminum in small amounts. Thus, Meunier²⁷³ reports 6 mg. of aluminum per kilogram of dry substance; Grendel²⁷⁴ found 0.09 mg. of copper per 100 g. of pulp and 0.07 mg. per 100 g. of peel; Bertrand and Benzon²⁷⁵ reported 2.8 mg. of zinc per kilogram of the edible por-

²⁷¹ F. C. Stratton and H. W. von Loesecke, *A Chemical Study of Different Varieties of Bananas during Ripening*. United Fruit Co., Research Dept. Bull. No. 32, 1930.

²⁷² A. R. Moss, *Analyst*, 62, 32 (1937).

²⁷³ P. Meunier, *Bull. soc. chim. biol.*, 17, 548 (1935).

²⁷⁴ F. Grendel, *Pharm. Weekblad*, 67, 913 (1930).

²⁷⁵ G. Bertrand and B. Benzon, *Bull. soc. hyg. aliment.*, 16, 457 (1928).

TABLE 33. ASH CONSTITUENTS OF DIFFERENT VARIETIES OF BANANAS²⁷¹ EXPRESSED AS PERCENTAGE OF FRESH PULP

Constituent	Gros Michel	Lady Finger	Lacatan	Plantain
Silica (SiO_2)	0.0238 $\pm$ 0.0014	0.0175 $\pm$ 0.0010	0.0288 $\pm$ 0.0017	0.0119 $\pm$ 0.0011
Sulfur (SO_3)	0.0115 $\pm$ 0.0003	0.0158 $\pm$ 0.0004	0.0135 $\pm$ 0.0005	0.0183 $\pm$ 0.0008
Calcium (CaO)	0.0093 $\pm$ 0.0002	0.0084 $\pm$ 0.0001	0.0144 $\pm$ 0.0003	0.0165 $\pm$ 0.0009
Magnesium (MgO)	0.0451 $\pm$ 0.0006	0.0526 $\pm$ 0.0044	0.0515 $\pm$ 0.0044	0.0577 $\pm$ 0.0014
Iron (Fe_3O_3)	0.000155 $\pm$ 0.000003	0.000197 $\pm$ 0.000002	0.000233 $\pm$ 0.000007	0.000296 $\pm$ 0.000041
Phosphorus (P_2O_5)	0.0764 $\pm$ 0.0017	0.0535 $\pm$ 0.0016	0.0827 $\pm$ 0.0015	0.1200 $\pm$ 0.0022
Chlorides (Cl)	0.0770 $\pm$ 0.0012	0.0393 $\pm$ 0.0007	0.0626 $\pm$ 0.0003	0.0609 $\pm$ 0.0014
Potassium (K_2O)	0.4203 $\pm$ 0.0036	0.3635 $\pm$ 0.0030	0.4205 $\pm$ 0.0025	0.4842 $\pm$ 0.0123
Sodium (Na_2O)	0.0684 $\pm$ 0.0042	0.0604 $\pm$ 0.0039	0.0379 $\pm$ 0.0023	0.0333 $\pm$ 0.0023

tion of the plantain (*M. paradisica*); an iodine content of from 5 to 200 parts per billion of the fresh fruit has been indicated.^{275a} More research could be carried out in this field, particularly from the standpoint of nutrition.

Although there are no marked differences between the total ash of the varieties investigated by Stratton and von Loesecke,²⁷¹ differences may be found between the varieties in their ash constituents (Table 33). Of particular interest are the sharply divided groups: Plantain-Lacatan and the Gros Michel-Lady Finger, with regard to calcium. It is not known, however, whether this grouping is due to coincidence or to selective absorption of the varieties. A slight correlation was also found between magnesium and protein content, *i.e.*, high protein value was accompanied by high magnesium content; an inverse relationship was noted between chlorides and starch.

Referring to Table 33, the figures after the $\pm$ signs represent the mean of duplicate analyses of each of eight samplings throughout the ripening period. Each sample was a composite of 10 loose fingers. Figures for the Gros Michel represent the mean of four analyses on the composite ash from 96 fingers removed at six stages of ripeness; those of the Lady Finger represent the mean of four analyses on a composite ash from 432 fingers removed at six stages of ripeness; and those of the Lacatan represent the mean of four analyses on a composite ash from 112 fingers removed at seven stages of ripeness.

M. Volatile Constituents

A comprehensive study of the volatile constituents of ripe bananas has never been published. The characteristic aroma and flavor develop during ripening and are probably due to certain alcohols and esters. Kleber²⁷⁶ found amyl acetate as a normal constituent of ripe bananas, but he made no attempt to isolate any of the odorous principles. Preliminary experiments²⁷⁷ have shown that the odorous constituents of the pulp of the ripe Lacatan consist

^{275a} *The Canned Food Reference Manual*. 2nd ed., American Can Company, New York, 1943.

²⁷⁶ C. Kleber, *Am. Perfumer*, 7, 235 (1913).

²⁷⁷ Unpublished data of the author.

essentially of the amyl esters of acetic and butyric acids, with appreciable amounts of acetaldehyde. In addition, very small quantities of ethyl and methyl alcohols were detected. The essential oil of the fruit, as extracted by means of ethyl ether from a concentrated distillate of the pulp, is a yellow, viscous oil at ordinary temperatures, and possesses in a small degree the odor of bananas. The odor increases in intensity upon the addition of water, but the watery extract has an insipid taste. The yield of oil from the pulp corresponded to 0.0013% of the weight of the fresh pulp.

N. Change in Pigments during Ripening

It is a well-known fact that, during maturation of the banana, the fruit changes in color from green to yellow (see color plate). The relationship between chlorophyll (a + b), xanthophylls, and carotene in the peel of the fruit during ripening has been studied.²⁷⁸

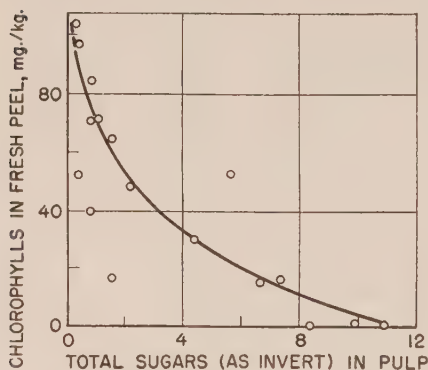
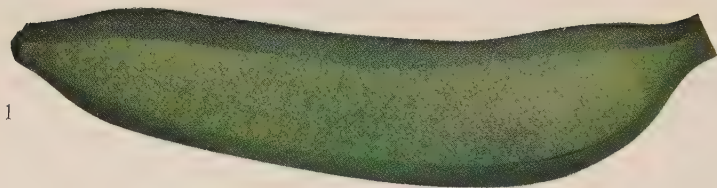


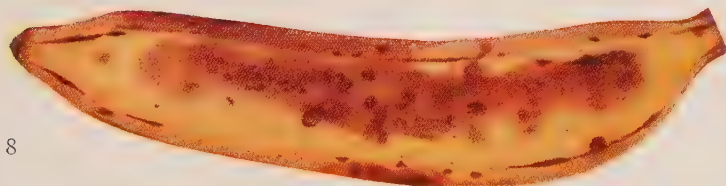
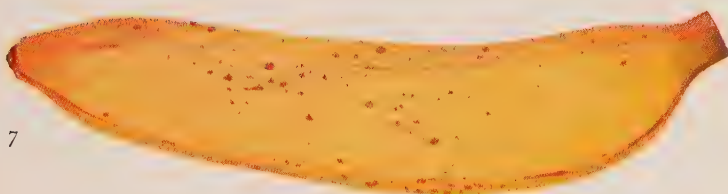
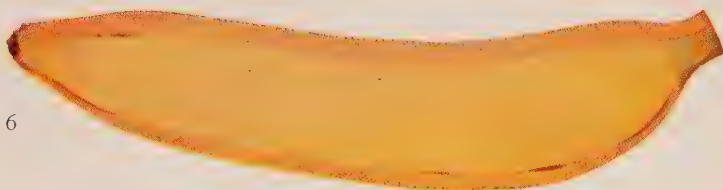
Fig. 27. The relation of chlorophylls in banana peel to total sugars (as invert) in the pulp.²⁷⁸

These are not the only pigments present, since during the process of separation there were indications of flavones and anthocyanins. These last two pigments are present in the cell sap, while chlorophyll, xanthophylls, and carotene are present in the plastids. The data obtained indicate that the chlorophyll content of the peel ranges from 102.9 to 51.7 mg. per kilogram of fresh peel in the unripe fruit at the time of discharge from the ship, and decreases as the fruit ripens (Table 34). Chlorophylls were shown to decrease as a

²⁷⁸ H. W. von Loesecke, *J. Am. Chem. Soc.*, 51, 2439 (1929).



The Ripening Banana :



Courtesy United Fruit Company

A Guide to the Stages of Ripeness

straight-line function of time. Total yellow pigments (xanthophyll plus carotene) remain approximately constant throughout ripening of the fruit. The quantity of xanthophylls was always greater than the amount of carotene, the range of the former being from about 5 to 7 mg. per kilogram of fresh peel, while the range of the latter was from 1.5 to 3.5 mg. per kilogram of fresh peel.

TABLE 34. CHLOROPHYLL, XANTHOPHYLL, AND CAROTENE IN THE PEEL OF BANANAS²⁷⁸ EXPRESSED IN MILLIGRAMS PER KILOGRAM OF FRESH PEEL

Days ^a	Chlorophyll (a + b)	Xanthophyll	Carotene	Total yellow pigments	Total sugar (as invert) in pulp, %	Series
0	94.5	5.21	1.57	6.78	0.51	I
2	15.5	5.45	1.90	7.35	1.64	
3	—	6.31	2.51	8.82	6.14	
4	0.0	6.57	1.71	8.28	9.92	
0	102.9	7.34	2.05	9.39	0.40	II
2	72.5	5.75	1.82	7.57	1.25	
3	48.7	5.91	2.27	8.18	2.24	
4	29.0	5.70	2.87	8.57	4.54	
5	0.0	3.95	3.56	7.51	11.16	III
0	51.7	6.61	1.54	8.15	0.58	
3	40.8	5.09	2.66	7.75	0.81	
4	14.4	5.41	1.67	7.08	7.63	
0	83.4	5.92	3.66	9.58	0.98	IV
1	52.5	7.02	2.44	9.46	5.64	
0	70.1	7.21	1.22	8.43	0.93	V
2	66.1	4.90	3.41	8.31	1.54	
3	14.1	5.15	3.39	8.54	6.52	
5	0.0	5.00	3.69	8.61	8.25	

^a Days from time of discharge from ship at Boston.

Since the publication of this work, the technique of estimating carotenoid pigments has been greatly improved, but there are no published data indicating a study of pigments of the fruit using the newer methods. Research, for instance, dealing with the amount and kind of carotene in the peel should yield results of practical significance. This pigment is undoubtedly of importance in the physiology of plants, but its exact function in the economy of the banana is unknown. The importance of carotene as a precursor of vitamin A is too well known to warrant further discussion.

O. Change in Vitamins during Ripening

Investigators have devoted their greatest attention toward the ascorbic acid content of the banana, while much less attention has been given to other vitamins that may be present in the fruit.

Harris and Poland²⁷⁹ have made a comprehensive study of the variations in the ascorbic acid content of the banana and found that this vitamin increased during ripening, but decreased in the overripe stage (Table 35). Thornton's data,²⁸⁰ on the other hand,

TABLE 35. ASCORBIC ACID CONTENT OF COSTA RICAN BANANAS AT VARIOUS STAGES OF RIPENESS²⁷⁹

Stage of ripeness	No. of analysis	Range of values, mg./g.	Av. value, mg./g.	Change, %
Green peel, hard pulp	10	0.058–0.049	0.053	—
Green peel with some yellow peel	15	0.066–0.053	0.058	9.4
Yellow more dominant in peel than green	15	0.144–0.038	0.063	18.9
Yellow peel, green tip	20	0.130–0.052	0.088	66.0
Completely yellow peel	20	0.132–0.056	0.091	71.7
Yellow, flecked with brown	18	0.143–0.089	0.111	109.4
Black peel with overripe pulp	7	0.054–0.010	0.032	–39.6

show that during ripening at 66.2°F. (19°C.) ascorbic acid increased slightly at the time of early development of yellow color, then fell gradually with complete yellowing to 10 to 12 mg. per 100 g. of pulp. The ascorbic acid content remained at this level through the period where brown specks developed on the peel and

TABLE 36. ASCORBIC ACID VARIATION IN NORMALLY RIPENED RIPE BANANAS FROM DIFFERENT SOURCES²⁷⁹

Origin	No. of analyses	Range of values, mg./g.	Av. value, mg./g.
Costa Rica	58	0.143–0.089	0.109
Honduras	30	0.102–0.096	0.100
Colombia	35	0.142–0.084	0.110
Ecuador	25	0.113–0.092	0.102

²⁷⁹ P. L. Harris and G. L. Poland, *Food Research*, 4, 317 (1939).

²⁸⁰ N. C. Thornton, *Contrib. Boyce Thompson Inst.*, 13, 201 (1943).

until more than 50% of the peel was brown and the pulp was soft. A further reduction of ascorbic acid then took place with continued browning, and finally blackening. Thornton used a different extracting medium than did Harris and Poland.

The average ascorbic acid content of the fruit, regardless of its tropical source was found to be relatively constant at 0.100 mg. per gram (Table 36).²⁷⁹

In using the bioassay method for determining ascorbic acid, Harris and Poland²⁸¹ found that the values did not agree with those obtained by dye titration. These workers indicated that a portion of the ascorbic acid in bananas existed as dehydroascorbic acid, and that, although this amount was practically constant, for accurate estimation of the acid in the fruit by dye titration, a reduction step must be included in the procedure. Part of the naturally occurring ascorbic acid is oxidized by enzymes to dehydroascorbic acid during preparation and manipulation of the material for analysis. That there are enzymes in bananas which bring about rapid destruction of ascorbic acid when the tissue is macerated in air, has been quite definitely proved by Thornton.²⁸² He found that oxidation in ascorbic acid may amount to 50% in one minute unless such concentrated acids as 1 *N*, 2 *N*, or 3 *N* sulfuric in conjunction with 0.25 *N* metaphosphoric acid are used. Harris and Poland²⁸¹ did not employ such concentrations and this no doubt accounts for the failure of their results to agree with Thornton's.

The retention of ascorbic acid in bananas during preparation of the fruit for the table is a matter of practical dietary importance. In this connection, Harris and Poland²⁷⁹ found that thin-sliced fruit exposed to room temperature lost some of its ascorbic acid. In about 5 hours the loss reached approximately 40 to 45% and remained constant for the remainder of the 22 hour test. When the fruit is cooked in the peel, almost all the ascorbic acid is retained.

Using the bioassay technique, Harris and Poland²⁸¹ reported that bananas contain from 71 to 95 international units (I. U.) of vitamin A per ounce; this would correspond to from 1.6 to 2.03 μ g. per gram of β -carotene. Angelo *et al.*²⁸³ reported a value of from

²⁸¹ P. L. Harris and G. L. Poland, *Food Research*, 2, 311 (1937).

²⁸² N. C. Thornton, *Contrib Boyce Thompson Inst.* 9, 273 (1938).

²⁸³ J. J. Angelo, C. Fuent, and M. Johnson, *J. Nutrition*, 31, 463 (1946).

TABLE 37. ASCORBIC ACID CONTENT OF BANANAS AS DETERMINED BY VARIOUS INVESTIGATORS

Investigator	Ascorbic acid, mg./g. of pulp
Lewis ^a	0.03-0.05
Givens <i>et al.</i> ^b	0.05
Jansen and Donath ^c	0.05-0.10
Eddy and Kellogg ^d	0.10
Grunninger ^e	0.05
Eddy ^f	0.05
Naeslund ^g	0.05
Dalldorf ^h	0.05
Birch <i>et al.</i> ⁱ	0.15
Davies and Ziegler ^j	0.044
Eddy ^k	0.24
Leverton ^l	0.073
Harris and Poland ^m	0.10
Harris and Poland ⁿ	0.053-0.111
Thornton ^o	0.10
Munsell ^p	0.068-0.071
De Caro and Locatelli ^q	0.08
Rose ^r	0.085-0.12
Schiaparelli and Buogo ^s	0.021
Anonymous ^t	0.031

^a H. B. Lewis, *J. Biol. Chem.*, 40, 91 (1919).

^b M. H. Givens, H. B. Cluggage, and E. G. Van Horne, *Proc. Soc. Exptl. Biol. Med.*, 18, 140 (1921).

^c B. C. P. Jansen and W. F. Donath, *Mededeel. Dienst. Volksgezondheid Nederland. Indië*, 225 (1925).

^d W. H. Eddy and M. Kellogg, *Am. J. Public Health*, 17, 27 (1927).

^e V. Grunninger, *Arch. Kinderheilk.*, 84, 284 (1928).

^f W. H. Eddy, *Am. J. Public Health*, 19, 1309 (1929).

^g C. Naeslund, *Upsala Läkarefören Förh.*, 36, 379 (1931).

^h G. Dalldorf, *J. Exptl. Med.*, 53, 289 (1931).

ⁱ T. W. Birch, L. J. Harris, and S. N. Ray, *Biochem. J.*, 27, 590 (1933).

^j B. P. Davies and M. Ziegler, personal communication to Harris and Poland.

^k W. H. Eddy, *Unpublished data*.

^l R. M. Leverton, *Food Research*, 2, 59 (1937).

^m P. L. Harris and G. L. Poland, *ibid.*, 2, 311 (1937).

ⁿ P. L. Harris and G. L. Poland, *ibid.*, 4, 317 (1939).

^o N. C. Thornton, *Contrib. Boyce Thompson Inst.*, 13, 201 (1943).

^p H. E. Munsell, *Food Research*, 10, 42 (1945).

^q L. De Caro and A. Locatelli, *Quaderni nutriz.*, 4, 32 (1937).

^r M. S. Rose, *Foundations of Nutrition*. Macmillan, New York, 1933.

^s P. Schiaparelli and G. Buogo, *Rev. clinica Pediatrica*, 33, 789 (1935).

^t Anon., *Pub. inst. nacl. nutrición Buenos Aires, Pub. cient. CNP*, 29, 9 (1945).

300 to 9200 $\mu\text{g.}$ per gram of carotene, the higher value being that for the Burro plantain. De Caro and Locatelli²⁸⁴ give a value of one biological unit of vitamin A per gram for bananas grown in Italian Somaliland. Since their term "biological unit" is vague, their values cannot be compared with those of other investigators.

De Caro and Locatelli²⁸⁴ report 0.6 $\mu\text{g.}$ of thiamin per gram for bananas grown in Italian Somaliland. Asenjo and co-workers^{284a} report an average thiamin content of Cuban bananas (*M. sapientum*) investigated as ranging from 34 to 48 $\mu\text{g.}$ per 100 g. of fresh pulp. Finkelstein and Sherman²⁸⁵ found a riboflavin content of 47.7 γ per 100 g. Asenjo and co-workers²⁸⁶ report the following riboflavin values for different varieties of *M. sapientum* L.:

Variety of <i>M. sapientum</i> L.	Riboflavin content, γ /100 g.
Gigantic	45-61
Apple	23-38
Fig	51-68

Elvehjem²⁸⁷ gives a riboflavin value of 0.080 mg. per 100 g. of pulp. More recent data for Brazilian bananas indicate a riboflavin content of 87 γ per 100 g. of pulp²⁸⁸; this value agrees with Elvehjem's figure.

Tepley *et al.*,²⁸⁹ using the microbiological method of Snell and Strong, found 0.61 mg. of niacin per 100 g. of fresh banana pulp. A niacin content of 1.209 mg. per 100 g. has been reported for Brazilian bananas.²⁸⁸

The lesser known vitamins have been investigated by Ansbacher,²⁹⁰ Evans,²⁹¹ Elvehjem,²⁸⁷ and Cheldelin and Williams.²⁹²

²⁸⁴ L. De Caro and A. Locatelli, *Quaderni nutriz.*, 4, 32 (1937).

^{284a} C. F. Asenjo, Oro de Borinquen Segundo, and H. Garcia de la Noceda, *Food Research*, 13, 94 (1948).

²⁸⁵ B. Finkelstein and H. C. Sherman, *J. Nutrition*, 21, 175 (1941).

²⁸⁶ C. F. Asenjo, H. Garcia de la Noceda, and P. Serrano, *Food Research*, 11, 137 (1946).

²⁸⁷ C. A. Elvehjem, *Handbook of Nutrition*. American Medical Association, Chicago, 1943, p. 216.

²⁸⁸ *Pub. inst. nacl. nutrición Buenos Aires, Pub. cient. CNP*, 29, 9 (1945).

²⁸⁹ L. J. Tepley, F. M. Strong, and C. A. Elvehjem, *J. Nutrition*, 23, 417 (1942).

²⁹⁰ S. Ansbacher, *Proc. Soc. Exptl. Biol. Med.*, 46, 421 (1941).

²⁹¹ H. M. Evans, *unpublished data*.

²⁹² *Univ. Texas Pub.* No. 4237, 1942 (from unpublished data, United Fruit Company, New York).

Evans reports the fruit to be a poor source of vitamin E (tocopherols). Ansbacher states that bananas are apparently devoid of vitamin K, and that they do not contribute to a K-vitamin synthesis. Elvehjem gives data showing that the edible portion of the fruit contains 0.070 mg. of pantothenic acid per 100 g. Unpublished data by the United Fruit Company, quoting Cheldelin and Williams, give the following content of the lesser known vitamins:

Vitamin	Content, mg./100g.
Pyridoxine	0.32
Biotin	0.0044
Inositol	34.0
Folic acid	0.095

Eddy and Kellogg²⁹³ were unable to find any evidence of vitamin D in the fruit. De Caro and Locatelli,²⁹⁴ on the other hand, report 0.2 I. U. of vitamin D per gram for bananas grown in Italian Somaliland. In the absence of adequate experimental data, it is not possible to evaluate these results. However, no one has ever been able to prove conclusively the presence of this vitamin in a plant product.

P. Enzymes in the Ripening Fruit

In 1893 Mierau²⁹⁵ proved that invertase was present in the ripe banana in significant amounts, and that true results could be obtained in the determination of sucrose only if this enzyme is destroyed prior to analysis. Tallarico²⁹⁶ stated that the ripening banana contained catalase, invertase, amylase, and protease. He found that the activity of these enzymes varied greatly during ripening of the fruit: catalase activity, for instance, was found to be great in the green banana.

Vines²⁹⁷ reported a proteolytic enzyme in the fruit. He was not sure of its physiological significance, but thought that possibly this enzyme would make feasible the distribution of elaborated

²⁹³ W. H. Eddy and M. Kellogg, *Am. J. Public Health*, 17, 27 (1927).

²⁹⁴ L. De Caro and A. Locatelli, *Quaderni nutriz.*, 4, 32 (1937).

²⁹⁵ F. Mierau, *Chem.-Ztg.*, 17, 1002; 1283 (1893).

²⁹⁶ G. Tallarico, *Arch. farmacol. sper.*, 7, 27 (1908).

²⁹⁷ S. W. Vines, *Ann. Botany*, 17, 244 (1903).

proteins. The enzyme would be similar in this respect to plant diastase (amylase) which facilitates transference of temporarily deposited starch. Of passing interest in this connection is a patent for the recovery of proteolytic enzymes from bananas and other fruits.²⁹⁸ The fruit is pressed to a milky consistency, allowed to stand, and the enzyme is precipitated with acetone.

Bailey²⁹⁹ found a protease of the erepsin type, but no peptonizing enzyme was detected, contrary to Tellarico's findings.

In an early paper Bailey³⁰⁰ reported that he was unable to find amylases in either green or partially ripe bananas, but in a later paper²⁹⁹ he reported amylase to be present in the early stages of ripening, persisting even in the overripe fruit. This enzyme has also been reported to be present in the green fruit.³⁰¹ Manion³⁰² has found it in the ripe fruit. Falk and McGuire³⁰³ could find no evidence of amylase: "It is possible that the ripening process, or the breaking down of starch is not merely an amyloclastic action as this is commonly understood, but involves a simultaneous or preliminary oxidation reaction."

Sastri and Row³⁰⁴ suggest that the peel of the fruit is probably the seat of amylase. This is based on their histological examination of the fruit showing that the disappearance of starch begins from the periphery and gradually extends toward the core. Their data also seem to indicate that the pulp of the fruit contains activators of amylase, for pulp extracts exhibit little or no activity, while a mixture of peel and pulp extracts showed a greater activity than either one alone.

It is possible that the apparent contradictory evidence relating to the presence of amylase may be due, at least in part, to the fact that diastase is precipitated or otherwise inactivated in the presence of tannin in the banana (Section H).

Invertase is present in the unripe fruit, but its activity is much more intense in the ripe fruit.²⁹⁹ This enzyme has been

²⁹⁸ C. Wada (to Mataemon Masuda), U. S. Pat. 1,959,750, May 22, 1934.

²⁹⁹ E. M. Bailey, *J. Am. Chem. Soc.*, **34**, 1706 (1912).

³⁰⁰ E. M. Bailey, *J. Biol. Chem.*, **1**, 355 (1906).

³⁰¹ F. C. Stratton, *unpublished data*, United Fruit Company.

³⁰² J. T. Manion, *unpublished data*, United Fruit Company.

³⁰³ K. G. Falk and G. McGuire, *J. Gen. Physiol.*, **3**, 595 (1921).

³⁰⁴ B. N. Sastri and G. R. Row, *Proc. Indian Acad. Sci.*, **B1**, 318 (1934).

rather thoroughly studied by Falk and McGuire³⁰⁵ and by McGuire and Falk.³⁰⁶ They obtained what they term soluble and insoluble invertase. The behavior of the enzyme, as far as *pH* for maximum action and temperature relation is concerned, is similar to that of yeast and potato invertase. There was a spontaneous increase in invertase action of banana extracts on standing or "aging." This increase varied considerably in magnitude and in some cases the original activity was almost doubled upon standing; and after

TABLE 38. ENZYMES REPORTED IN BANANAS

Date reported	Investigator	Enzyme reported
1893	Mierau	Invertase
1903	Vines	Protease
1907	Vinson	Catalase, invertase, amylase, protease
1908	Tellarico	Invertase, catalase, amylase, protease
1909	Moore and Whitney	Peroxidase
1911	Langworthy and Milner	Lipase, catalase, amylase, invertase, protease
1912	Bailey	Amylase, protease, lipase, peroxidase, invertase
1920	Onslow	Peroxidase, oxygenase
1921	Falk and McGuire	Invertase
1929	Stratton	Amylase
1933	Nelson and Hemperty	Phosphatase
1933	Manion	Amylase
1936	Dale	Phosphatase
1937	Stone	Ascorbic acid oxidase
1942	Bartók	Ascorbic acid oxidase

reaching a maximum value, decreased again. Apparently, the state of maturity of the fruit at the time of extraction influences this increase in activity. McGuire and Falk³⁰⁶ suggest the possibility of the formation of a new enzyme. During ripening, invertase increases, and it is conceivable that banana extracts contain material which, in the absence of the life process, "spontaneously" forms a new enzyme. The increase in activity of the extracts, followed by a decrease, may be accounted for by the fact that the invertase in the extracts loses its activity steadily, that the formation of a new

³⁰⁵ K. G. Falk and G. McGuire, *J. Biol. Chem.*, 54, 655 (1922); *J. Gen. Physiol.*, 3, 595 (1921).

³⁰⁶ G. McGuire and K. G. Falk, *J. Am. Chem. Soc.*, 45, 1539 (1923).

enzyme takes place rapidly at first and gradually decreases in rate as the available material is exhausted, and that, finally, destruction of the enzyme is more rapid than formation of the new enzyme.

Falk and McGuire also show that banana extracts have the property of forming gels when mashed and filtered pulp is used as a substrate. This gel-forming property and the invertase activity

TABLE 39. CHEMICAL COMPOSITION OF DIFFERENT VARIETIES OF RIPE BANANAS^a EXPRESSED AS PERCENTAGE OF FRESH PULP

Constituent	Gros Michel	Lady Finger	Lacatan	Plantain	Red ^c banana
Moisture	75.9	70.6	71.6	63.8	73.3
Reducing sugars	10.73	6.19	8.15	18.89	4.10
Nonreducing sugars	6.12	13.38	10.01	0.00	16.08
Starch	2.93	4.13	6.54	11.69	4.12
Total carbohydrates	19.78	23.70	24.70	30.58	24.30
Protein	0.81	1.49	1.04	1.16	0.48
Crude fat	0.47	0.30	0.40	0.30	0.24
Pectin	0.34	0.57	0.41	0.43	0.62
Protopectin	0.34	0.29	0.35	0.37	0.43
Ash	0.76	0.70	0.77	0.85	0.84
Acidity, cc. ^b	4.46	4.27	4.06	9.00	4.05

^a These analyses are for fruit the peel of which had developed a full yellow color.

^b Cubic centimeters of *N* NaOH required to neutralize 100 grams of pulp.

^c Unpublished data, J. T. Manion, United Fruit Co., Research Dept., 1933.

of the fruit are due to different substances, made evident by the fact that the gel-forming substance is more soluble in water and less soluble in salt solution than the invertase substance. Both invertase and the gel-forming property are destroyed by boiling. Under certain specific conditions, the molecular aggregates, or micellae, forming the gel, include within themselves the entire amount of the invertase present. These workers have described in detail the preparation and properties of banana gel.³⁰⁷

Lipase has been reported in both the ripe and unripe banana.³⁰⁸

³⁰⁷ G. McGuire and K. G. Falk, *J. Gen. Physiol.*, **4**, 437 (1922).

³⁰⁸ E. M. Bailey, *J. Am. Chem. Soc.*, **34**, 1706 (1912).

Bailey³⁰⁸ reported the presence of peroxidase in all stages of ripeness of the fruit. Onslow³⁰⁹ found peroxidase and oxygenase in both the peel and pulp of bananas. The oxygenase of both peel and pulp catalyzes the oxidation of catechol, artificially supplied, with great rapidity followed by a blue color on adding guaiacum. The peel oxygenase also activates the oxidation of its own aromatic compounds with the production of a blue color when guaiacum is added.

Spruyt,³¹⁰ Bartók,³¹¹ and Stone³¹² have reported the presence of ascorbic acid oxidase. Stone found that the minced fruit loses its indophenol reducing power and is able to oxidize the ascorbic acid of orange juice. It will be recalled (see Section N) that Thornton found that the fruit contained an enzyme capable of destroying ascorbic acid, and, unless the tissue was extracted with a sufficiently strong acid, erroneous results were obtained in the determination of ascorbic acid.

Nelson and Hemperty³¹³ and Dale³¹⁴ found a phosphatase in the banana. Nelson and Hemperty also noted carboxylase. Dale's researches indicated that during the ripening process both fructose diphosphate and a hexose monophosphate are probably present in the fruit.

Bailey³¹⁵ was unable to find dextrinase or lactase in bananas. While it was found that banana tissue will hydrolyze raffinose, the presence of raffinase could not be demonstrated.

³⁰⁸ M. W. Onslow, *Biochem. J.*, **14**, 541 (1920).

³¹⁰ J. P. Spruyt, *Chem. Zentr.*, 1940, **II**, 227.

³¹¹ H. A. Bartók, *Biochem. Z.*, **311**, 418 (1942).

³¹² W. Stone, *Biochem. J.*, **31**, 508 (1937).

³¹³ J. M. Nelson and C. Hemperty, *J. Am. Chem. Soc.*, **55**, 1102 (1933).

³¹⁴ N. I. Dale, *Australian J. Exptl. Biol. Med. Sci.*, **14**, 329 (1936).

³¹⁵ E. M. Bailey, *J. Am. Chem. Soc.*, **34**, 1706 (1912).

TRANSPORTATION OF BANANAS

After the fruit has been harvested as previously described (Chapter III), it is transported by the "backer" to the nearest packroad or tramline. If the harvesting has not taken place near a tramline, the fruit is packed out on mules. In some instances the bunches are carried out by aerial conveyors. In other cases the fruit is loaded directly into the tram cars for transportation to the nearest railroad.

The fruit is transferred to railroad cars at the railroad running into the plantation. When there is a short waiting period for the cars, the bunches of fruit are placed alongside the track on platforms constructed of turf or wood and covered with leaves to protect the fruit.

The cars of fruit are switched to the dock at the loading port where loading starts immediately and continues day and night until the ship is loaded. A cargo of 85,000 bunches will require from 12 to 15 hours for loading.³¹⁶ The fruit is inspected before loading, and ripened fruit or that showing excessive fullness is culled out. On board ship, the fruit is stowed away in various compartments or bins. The bananas are stowed resting on the butt end of the stalk, in from one to three tiers. Adequate space is left between bunches and hands for air circulation. The bins are made of wooden bars to keep the fruit from shifting during the voyage.

After the bins and compartments are loaded, refrigeration is started to reduce the temperature to 57°F. (13.9°C.), if the ships are so-called refrigerated ships. This type of vessel is used when the sea voyage will be prolonged. Ships for short hauls are ventilated and not provided with refrigeration facilities.

³¹⁶ *The Story of the Banana*. United Fruit Company, Boston, 1941.

The refrigeration machinery of the ship, after removing the "field heat," is mainly engaged in neutralizing two sources of heat: (1) respiration of the fruit, and (2) heat added to the air stream by the huge fans needed to circulate the air at a rate sufficient to carry off the heat of respiration without a large temperature gradient.³¹⁷ Reynolds³¹⁸ states that in the early stages of cooling the amount of heat given off by the average cargo of bananas is about 8 million B.t.u. per hour. It has been estimated³¹⁷ that at the time of arrival at port of discharge bananas have a heat production of the order of 150 B.t.u. per ton per hour.

During transportation, bananas may be subject to rots which result in losses of fruit. Von Becze³¹⁹ has described the mechanism of the rotting of the fruit during transit, and has listed 33 different molds considered important in banana rots. Through the action of enzymes formed by molds, the cell walls, middle lamella, and cell contents are destroyed. The fruit thus decays. Rotting first manifests itself externally in the form of brownish spots, streaks or a depression in the peel. These spots rapidly spread and assume a black color. On their upper surface they appear mostly as white, yellow, rose, or gray mycelium threads, then as black, white, red, rose-colored, or green mold spores with the consistency of fine dust. The affected part is usually soft, moist, and foul-smelling. The edges of the decomposed places, especially the peel of green or half-ripe fruit, assume reddish yellow streaks. The rotting can extend to large groups of fingers on the bunch, upon individual hands, but seldom upon the entire bunch. Rotting can be located on the entire surface so that only the fruit peel, for example, the surface of the peel, will be destroyed; but it can also penetrate to the flesh or into the interior of the peel. This condition depends partly on the peculiarity of the destructive mold, and partly on its degree of development.

Mold growth would also probably tend to speed ripening, because certain molds have the property of evolving ethylene. Miller, Winston, and Fisher³²⁰ and Biale³²¹ have shown that the fungus

³¹⁷ A. J. M. Smith, *Dept. Sci. Ind. Research (Brit.)*, *Rept. Food Invest. Board*, 1932, 145.

³¹⁸ P. K. Reynolds, *The Banana*. Houghton Mifflin, Boston, 1927.

³¹⁹ G. von Becze, *Zentr. Bakt. Parasitenk., Abt. II*, 86, 381 (1932).

³²⁰ E. V. Miller, J. R. Winston, and D. F. Fisher, *J. Agr. Research*, 60, 269 (1940).

Penicillium digitatum is capable of producing ethylene. Whether the molds causing the characteristic rots in bananas evolve ethylene is, of course, a matter of speculation, since published experimental evidence is lacking.

Von Becze³²² has estimated the loss of fruit during sea voyage as amounting to from 5 to 8%, and this often mounts to a ripening loss of from 20 to 25%. Tomkins and Woodman,³²³ on the other hand, state that it is difficult to estimate the extent of wastage.

Molds find the moist storage space in the ships a favorable place for growth during the voyage. They penetrate into the banana through wounds that may have been suffered during harvesting and loading. The large cut surface of the upper end of the stalk is the main ingress of organisms which later infect the fingers along the stalk. Main stalk rot (a downward rotting from the cut end of the stalk), sometimes improperly described as *stem end rot*, causes trouble when the fruit is removed from the holds at overseas ports. The organisms causing this condition are *Thielaviopsis paradoxa*, *Botryodiplodia theobromae*, and *Gloeosporium musarum*.

The term "stem end rot" is more properly applied to a decay of the "fingerstalks" or pedicels of individual fingers and is a principal cause of "dropping fingers" during ripening. It is due primarily to the flexing and creasing of the pedicels near the point of attachment during transportation and handling. Death of the tissues follows, with subsequent fungal infection which is thus the result rather than the cause of the trouble. Santa Marta fruit, pre-disposed to this trouble because of structural weakness, was given complete mechanical protection by crating in the field, carried all the way to England, ripened there in perfect condition and entirely free from stem end rot. The control fruit in the same cargo was all badly affected.³²⁴

Wardlaw and McGuire³²⁵ believe that losses from rot could be considerably reduced by: (1) cutting the stalks long when

³²¹ J. B. Biale, *Calif. Citrograph*, 25, 186 (1940).

³²² G. von Becze, *Tropenpflanzer*, 35, 419 (1932).

³²³ R. G. Tomkins and R. M. Woodman, *J. Soc. Chem. Ind.*, 49, 285T (1930).

³²⁴ A. H. Slocum, *private communication*, United Fruit Co., Research Dept., New York.

³²⁵ C. W. Wardlaw and L. P. McGuire, *Tropical Agriculture Trinidad*, 7, 183 (1930).

harvesting; (2) freshly cutting the stalk at the dock and thoroughly smearing the cut end with Vaseline; (3) starting refrigeration as soon as possible after loading; (4) rapid cooling of the cargo within 12 hours, the fans delivering cold air at 53°F. (11.7°C); and (5) upon arrival at port of discharge, fruit showing rot should be ripened as quickly as possible; high ripening temperatures should not be used.

Numerous other workers have attempted to prevent rotting of the stem by special treatment of the cut stalk. Tomkins and Woodman,³²⁶ based on their laboratory work, recommend coating the butt end of the stalk with a mixture of paraffin, Vaseline, or fats of low melting point. The effectiveness of such treatment was not demonstrated on a commercial scale. A patent covers this procedure.³²⁷ Von Becze³²⁸ smeared the end of the stalk with clay over which was bound cotton wadding, and subsequently dipped the end of the stalk into a soda solution. Infections were seldom found under such treatment despite the fact that the clay was brittle. Infection was found, however, on the side of the stalk a few centimeters from the place where the cotton wadding was held by a string.

Von Becze also tried smearing the stalk end with a mixture of paraffin and wool grease, with and without 5% phenol. The cut surface was then inoculated with spores of *Thielaviopsis paradoxa* and *Fusarium semitectum* Berk et Rav., var. *Maius* Wr. Mold developed in the inoculated stalks not smeared, and penetrated to a depth of from 5 to 8 cm. into the interior of the stem, even covering the sides of the stem. Spores did not germinate on the smeared stalks and no decomposition was apparent. On the basis of his experiments von Becze recommends the following treatment. The worker cuts the lower thicker part of the fruit stem 8 to 10 cm. from the oldest finger, with a single stroke of a sharp knife. The upper thinner end of the stalk is then cut off where the young, undeveloped, lower small hand—and the easiest to decompose—is located. Both fresh cut surfaces are smeared 2 to 4 cm. thick with a paste consisting of a mixture of plaster of Paris and cement. The

³²⁶ R. G. Tomkins and R. M. Woodman, *J. Soc. Chem. Ind.*, 49, 285T (1930).

³²⁷ R. G. Tomkins and R. M. Woodman, Brit. Pat. 348,755, May 21, 1931.

³²⁸ G. von Becze, *Zentr. Bakt. Parasitenk., Abt. II*, 86, 381 (1932).

smearing should continue 2 to 3 cm. down the side of the stem. After the paste has dried for 2 to 3 hours, the stem is ready for shipment. The length of time required for the paste to dry would seem to preclude its commercial use under most conditions. Von Becze also suggested painting the cut stalk with a thick solution of slaked lime. However, pectin-decomposing organisms find a favorable growth medium in this alkaline surface, developing acid and quickly destroying the fibers. The organisms can easily penetrate into the stalk and from there to the fruit.

The sea voyage from Central America to New Orleans, Mobile, or Galveston in the United States requires from 3 to 5 days; to Boston, New York, Philadelphia, or Baltimore, from 5 to 7 days. Refrigerated ships are not always used on short hauls, such as those to New Orleans. A recent development has been the transportation of bananas by air.

The fruit is unloaded by pocket elevators, similar to those used for loading at tropical ports. Pocket elevators are supplemented by conveyor belts to save labor. Sometimes the fruit may be carried directly to the door of the refrigerator cars by such conveyors. Or the cars may be on a car float alongside the ship.

Refrigerated cars in the United States are equipped with slatted floor racks which provide an air space of from 3 to 5 inches under the load. The bulkheads and doorways are papered to direct the airflow uniformly throughout the load. Motor trucks are used for short hauls. In loading the fruit into the cars or trucks, the bunches are placed upright resting on the butt end, and are stowed in a manner to give a tight load to prevent shifting and bruising. A complete train usually consists of from 20 to 60 cars which are inspected before dispatching "by messengers." These messengers may accompany the shipment, or they are placed at strategic locations along the route of shipment in order to keep in close touch with the fruit during transportation, and to insure safe arrival at its destination. They inspect the cars, take temperature readings, report weather conditions, and instruct the railroad as to proper ventilation, icing, or heating.

During the summer, the cars are often iced; in winter they are preheated and heated during loading by portable oil stoves. While the cars are in transit or held on sidings, they are heated

by portable charcoal heaters installed in the bunkers. In the spring and fall, the cars are usually carried under various stages of ventilation, accomplished by adjusting the hatches and plugs.

The distribution of bananas in the United States is generally as follows.³²⁹ Imports at northern Atlantic ports are distributed mainly in the eastern states, territory north of the Ohio River and North Carolina, as far west as Columbus, Toledo, and Detroit. Imports at Gulf ports, Jacksonville, and Charleston are sent throughout the section south of the Ohio River and Virginia, also the Central West including a portion of the country lying West and North of the Mississippi River. Fruit arriving at Pacific coast ports is marketed in states west of the Rockies. A considerable quantity of fruit from Mexico is also normally shipped by rail, through Texas and Arizona. Bananas are imported directly into Canada through the eastern ports of St. John, Halifax, and Montreal, and through the Pacific ports of Victoria and Vancouver. In the summer months, the fruit may be sent to points even beyond the Arctic Circle.

The sea voyage to Great Britain requires about 16 days from the producing areas. In Great Britain, the rail haul is short, the longest being about 615 miles (Avonmouth to Inverness). Twenty-four hours after the fruit has arrived at an English port, it has been distributed to wholesalers. Normally, bananas are marketed in all European countries except Russia. Bergen (Norway) has a regular banana connection with Iceland. From Trondhjem (Norway) fruit is distributed as far north as Spitzbergen.

Bananas are not displayed abroad on the stalk as is the custom in the United States. They are cut into hands after ripening, packed in standard boxes and transported to retailers in the small towns and villages.

In the United States, ripe bananas are sometimes cut from the stalk and the hands are packed in boxes for distribution to the retail trade. Advantages of boxing are said³³⁰ to be (1) protection against chilling; (2) reduced delivery expense because the boxes are more convenient to handle; (3) low container cost per trip—

³²⁹ *The Story of the Banana*. United Fruit Company, Boston, 1941.

³³⁰ *Boxing Bananas*. Equip. Dept. Circ. 16, Fruit Dispatch Company, New York, 1933.

the wooden box is a returnable package; (4) assurance that retailers will display the fruit by hands, and mass display will attract more attention; (5) low packing costs; and (6) bruising of the fruit is reduced.

The boxes used may be of the returnable type consisting of a rectangular wooden box, or a nesting plywood box. The latter is considered the most satisfactory, and, although its cost is greater than the rectangular box, it has a longer life and can be nested when empty thus occupying less space on the return trip. Non-returnable boxes are kraft or jute cartons constructed of corrugated fiber of 200-pound bursting strength. Packing material consists of dried sea grass or shredded newspaper which is well loosened up and spread to a depth of from 2 to 3 inches on the bottom of the box and then up around the sides and ends.

The fruit, ripened to about the green tip stage, is loaded on trucks and the hands are cut from the stalk. Generally nines or eights are preferred for boxing. The first hand is placed flat side down with the crown against the corner of the box; or the first hand is placed with the flat side against the end of the box and crown down. The remaining hands are placed in the box shingle-fashion with the crowns on the bottom of the box, fingers pointing upward and in a sloping direction toward the first hand. Sometimes all the hands are packed with the fingers pointed down; this facilitates removal of the hands from the box and makes it easier to avoid breaking the fingers. Forty pounds of fruit are packed to a box, and 100 pounds of fruit on the stem will yield 85 pounds of salable fruit.

The stalk of the fruit is a waste product, containing over 90% water and considerable potash in the ash (Table 40). In the United States the stalks are usually discarded as waste and serve no useful purpose. One large operator of boxed bananas crushes and shreds the stalks by passing them through a mill similar to a cane mill. This treatment reduces the moisture content to about 70%. The material is then sold locally as a mulch. The liquor pressed from the stalk is rich in potassium salts, but no effort is made to evaporate the liquid and crystallize the salts.

In China, the cooked stalk is believed to be useful in the eradication of the kidney worm (*Stephanurus dentatus*) from pigs.

Marsh and Kanagaratnam^{330a} investigated this belief and partially confirmed it, for they found a higher percentage of healthy livers and kidneys in the carcasses of infested pigs who received cooked stalks in their diet, than in infested pigs not receiving cooked stalks.

TABLE 40. COMPOSITION OF BANANA STALKS^a

Fruit variety	Moisture, %	Solids, %	Ash, %	Potash (K ₂ O) in the ash, %
Lacatan	92.75	7.25	2.16	62.1
Apple plantain	92.73	7.27	1.51	63.6
Horse plantain	91.10	8.90	2.00	60.9
Congo	94.08	5.92	2.04	60.9
Lady Finger	94.62	5.38	1.86	62.4
Gros Michel	92.40	7.60	2.14	57.6
Bluefield	93.48	6.52	—	63.3
Cavendish	93.99	6.01	1.92	53.8
Bumulan	93.68	6.32	1.86	—
Bungulan	93.99	6.01	2.00	61.0

TABLE 41. COMPOSITION OF THE ASH OF BANANA STALKS

Constituent, %	Source of data		
	(a)	(b)	(c)
Silica (SiO ₂)	9.61	2.81	3.99
Iron (Fe ₂ O ₃)	0.16	—	—
Aluminum (Al ₂ O ₃)	3.49	—	—
Calcium (CaO)	1.69	0.12	0.19
Magnesium (MgO)	1.68	0.07	0.09
Potassium (K ₂ O)	45.90	64.23	60.36
Sodium (Na ₂ O)	Trace	0.46	1.11
Sulfur (SO ₃)	2.10	4.17	2.24
Carbon dioxide (CO ₂)	31.11	26.11	27.12
Chlorides (Cl)	1.52	1.57	2.47
Phosphorus (P ₂ O ₅)	2.74	0.34	1.97
<i>Total</i>	<i>100.00</i>	<i>99.88</i>	<i>99.54</i>

(a) R. H. Ellis, *J. Soc. Chem. Ind.*, 35, 456 (1916).

(b) H. E. Billings and A. W. Christie, *J. Ind. Eng. Chem.*, 9, 153 (1917).

(c) Unpublished data of the author.

^{330a} T. D. Marsh and N. Kanagaratnam, *Malayan Agr. J.*, 30, No. 2, 55 (1947).

BANANA PRODUCTS

Under normal economic conditions, there is a supply of bananas not suitable for shipment as fresh fruit; or the fruit may consist of rejects culled upon unloading at the port, or from ripening rooms. During World War II there was also an oversupply in many banana-producing countries due to lack of shipping. In order to utilize these oversupplies, manufacture of banana products was resorted to in many areas of production, as well as in countries consuming the fresh fruit. However, production of such products is not of great economic importance except, perhaps, locally and they represent an insignificant part of bananas entering international commerce. For instance, in 1944 about 30 million bunches (1,500,000,000 pounds) of bananas were imported into the United States and only 1,439,488 pounds of dried bananas, or less than 0.1% of the bunches imported.

The chief products made from the fruit are flakes, figs, powder, flour, jam, or pastes. Brazil, for example, has produced such commodities for many years. In processing, bananas lose much of their flavor and the American public has not readily accepted these different products from the fruit.

A. Banana Flour and Banana Powder

These are perhaps the most important products, and may be prepared from both unripe and ripe fruit. The commodity made from the former is characterized by its high starch and low sugar contents, while that from the latter has a high sugar and a low starch content (Table 42).

TABLE 42. COMPOSITION OF BANANA FLOUR AND POWDER

Constituent, %	Source of data							
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Water	11.10-14.21	12.53-13.52	2.80-13.65	10.88	14.7	10.3-10.9	15.29-20.56	2.59-12.08
Protein	2.69-4.00	3.85-4.11	2.44-2.64	—	2.9	2.8-4.9	3.78-4.17	4.09-4.85
Fat	0.22-0.83	0.90-1.02	—	—	—	0.40-0.90	—	0.61-1.91
Sucrose	—	0.69-1.25	1.58-57.94	3.48	0.6	—	1.70	2.28-33.25
Reducing sugars	—	0.98-4.46	0.98-23.72	—	0.4	—	2.22-60.80	0.95-15.62
Starch	—	66.80-70.18	7.19-77.82	60.42	66.1	—	3.57-72.73	29.87-69.35
Total carbohydrates	79.04-84.83	71.85-72.51	70.93-88.85	—	67.1	79.6-83.13	66.07-74.95	72.58-78.74
Ash	2.23-2.92	3.06-3.12	1.49-4.31	2.64	2.2	2.00-3.00	2.93-3.21	3.05-3.09
Fiber	0.72-1.50	—	—	0.72	0.5	—	1.65-2.27	0.73

(a) C. H. Wright, *Trop. Agr., Trinidad*, 60, 53 (1923).(b) G. Fabiani, *Quaderni Nutriz.*, 6, 209 (1939).(c) A. Carteni, S. Perrelli, and A. Piergrosi, *ibid.*, 4, 310 (1937).(d) H. H. Cousins, *J. Jamaica Agr. Soc.*, 5, 322 (1901).(e) V. Marciano and A. Muntz, *Compt. rend.*, 88, 156 (1879).(f) K. C. Jacob, *Madras Agr. J.*, 29, 217 (1945).(g) R. Reich, *Z. Untersuch. Lebensm.*, 22, 208 (1911).(h) H. W. von Loesecke, *J. Chem. Ed.*, 7, 1537 (1930).

Banana flour, or at least the dried fruit, has been known for centuries. Su Sung³³¹ in his T'u-ching pên-ts'ao' (11th century) states "the sweetest kind can be dried in the sun and sent to distant places. Preserved banana is considered a delicacy in the North." Fan Ch'êng-ta,³³¹ in *Kuei-hai yü-hêng chih* (12th century) said "These fruits are called *chiao-tzu*, or *niu-chiao-tzu*. They can be preserved by being soaked in sugared plum juice, dried, and then pressed flat. Thus cured they retain a little frost on the outside and taste sweet and sour, and are known as *pa chiao kan* (dried banana)."

TABLE 43. CHEMICAL COMPOSITION OF BANANA FLOUR FROM FRUIT OF VARIOUS GRADES OF MATURITY^a

Maturity	Water, %	Protein, %	Total sugars, %	Reducing sugars, %	Sucrose, %	Starch, %	Cellu- lose, %	Fat, %	Ash, %
Green	8.18	3.78	87.25	5.68	5.76	67.51	4.22	1.15	3.23
Semigreen	5.58	3.84	87.62	31.80	7.26	43.35	4.25	1.11	3.28
Semimature	7.73	3.81	83.85	41.50	3.23	35.00	3.58	1.02	3.17
Full mature	6.81	3.66	85.00	41.25	13.25	25.98	3.61	1.13	3.19

^a Experimental runs of fruit dehydrated at 113–122° F. (45–50°C.). Compiled from data of G. Fabriani, *Quaderni Nutriz.*, 6, 209 (1939).

Specific mention of banana flour as we know it today may be found in Stanley's *In Darkest Africa*.³³² "The Awamba understood the art of drying bananas over wooden gratings for the purpose of making flour. . . . If only the virtues of the flour were publicly known, it is not doubted that it would largely be consumed in Europe. For infants, persons of delicate digestion, dyspeptics, and those suffering from temporary derangement of the stomach, the flour properly prepared would be of universal demand. During my two attacks of gastritis, a light gruel of this, mixed with milk, was the only matter that could be digested."

One year after the publication of Stanley's book, a paper by Reichelt³³³ mentions a nourishing and pleasant-tasting meal pre-

³³¹ P. K. Reynolds and C. Y. Fang, *Harvard Univ. J. Asiatic Studies*, 5, 165 (1940).

³³² H. M. Stanley, *In Darkest Africa*. Vol. II, Scribner, New York, 1892, p. 261.

³³³ G. Reichelt, *Botan. Centr.*, 56, 314 (1893).

pared from unripe bananas. He describes the product as being white in color with dark red flecks. A later paper by Kindt³³⁴ mentions the preparation of flour from green bananas by drying the fruit in the sun and subsequently grinding and bolting. Burns³³⁵ claimed that the sun-dried product was superior to that obtained by dehydration with heat. This contention can hardly be held valid at the present time with recent advances in dehydration technology.

Flour prepared from green fruit often has a peculiar violet-like flavor and aroma. Sornay³³⁶ suggests adding vanilla or a similar material to improve the flavor.

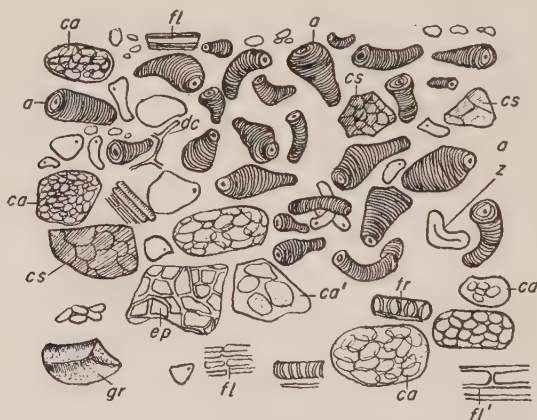


Fig. 28. The elements in banana flour: (a) isolated starch granules; (ca) cells full of normal starch; (ca') cells full of starch in paste form; (cs) colored cells bordering secretory canals; (dc) cellular debris; (ep) epicarp debris; (fl) bast fibers; (fl') pericyclic fibers of large fibrovascular bundles; (tr) trachea; (gr) debris of the secretory canal; (z) split grain.^{338a}

The method of preparing banana flour will vary in different producing countries. The technique used in the tropics is in general rather primitive. Kulkarmi³³⁷ describes a method used at one time in India, and which is probably used in certain regions of that country even today. The dry yard is prepared by beating the ground with a wooden plank, then plastering the ground with a mixture

³³⁴ L. Kindt, *Tropenpflanzer*, 11, 474 (1907).

³³⁵ W. Burns, *Agr. J. India*, 15, 166 (1920).

³³⁶ P. de Sornay, *Rev. agr. Maurice*, 5, 1 (1928).

^{338a} From Hanausek, *Z. Untersuch. Lebensm.*, 20, 215 (1910).

³³⁷ L. B. Kulkarmi, *Agr. J. India*, 6, 289 (1911).

of cowdung and water. A mat is spread on the ground thus prepared and the peeled fruit is placed on the mat. At night the fruit is gathered in a heap and covered with plantain leaves and a mat. It requires about 4 days to complete drying using this method. The sanitary aspects of the procedure leave much to be desired.

A more recent method is described by Ward.³³⁸ The fruit is peeled by Chinese coolies, and is then sliced on a foot-driven slicing machine. The thin slices ($\frac{1}{12}$ in. thick) are given a preliminary drying in the sun; then drying is completed by tray dryer at a temperature no higher than 122°F. (50°C.) for 24 hours.

Burns and Joshi³³⁹ made use of a drying box in their work in India. The box is similar to a show case with glass top and vents. A cane frame upon which the fruit rests is inside the box. The fruit is peeled and scraped with a bamboo scraper to get rid of the "strings" (see page 32). When the temperature falls below 95°F. (35°C.) in the sun, the vents in the box are closed with a bung. At night the entire box is covered with gunny sacks; if rain is threatened, a tarpaulin is used for covering. The fruit is turned daily to expose a fresh surface to the sun. Final drying is accomplished by placing cardboard over the glass, the purpose of this being to keep the fruit from darkening. It is interesting to note that in the locality where Burns and Joshi carried out their drying (at Kirkee), the annual rainfall amounted to only 27 inches.

Roudier and Lavollay³⁴⁰ have described the more modern methods used in the tropics. The carefully selected fruit is peeled by hand and is then sulfured (200 mg. of sulfur dioxide per 100 g. of fruit). The sulfured fruit is then dehydrated in tunnel or cabinet dryers at temperatures of between 140° and 167°F. (60° to 75°C.) with a relative humidity of between 20 and 25%. Wood is used as a fuel in Algiers, while bagasse is utilized in the Antilles. DaSilveira^{340a} suggests that in place of sulfuring the fruit be dipped in 1% citric acid solution to prevent discoloration. He gives a yield of from 20 to 30%, based on weight of the fresh, unpeeled fruit.

Most of the dehydrated bananas produced in the United

³³⁸ F. S. Ward, *Malayan Agr. J.*, 18, 138 (1930).

³³⁹ W. Burns and P. G. Joshi, *Agr. J. India*, 15, 166 (1920).

³⁴⁰ H. Roudier and J. Lavollay, *L'Industrie de la Banane Séchée*. Institut des Fruits et Agrumes Coloniaux, Sér. Techn. No. 1, Paris, 1945.

^{340a} A. H. DaSilveira, *Chacaras e Quintais*, 73, 440 (1946).

States and Brazil are prepared from the ripe fruit and should therefore be classed as banana powder and not flour. In general, the powder is made by passing the peeled fruit through a meat chopper to obtain a slurry which may be dried on steam-heated drum dryers. Double drums are preferable, and the distance between the drums must be carefully adjusted to variations in the ripeness of the fruit. If not properly adjusted, the product may come from the drums as a sticky mass, or it may be too crumbly. The slurry may also be spray dried, but losses (wall and entrainment) may be excessive.³⁴¹ Spray drying is also an expensive method of dehydration because of the large heat losses.

The drum-dried product comes from the drums in the form of flakes. In the United States, the flakes are ground and sometimes bolted. The Brazilian product is usually marketed as flakes without subsequent grinding.

Banana powder (from ripe fruit) is used chiefly in therapeutics and in the preparation of beverages of the malted milk type. Its therapeutic value is chiefly in the treatment of celiac disease, sprue, and other forms of carbohydrate intolerance of this nature. It also finds use in the adult diet for the treatment of certain intestinal disturbances.

The use of banana flour (from unripe fruit) in the United States is not great. Its main use in other countries has been in the preparation of bread. This was mentioned in an anonymous article appearing nearly 40 years ago.³⁴² Because banana flour contains no gluten, the loaf obtained would have little volume if banana flour were used alone. It is therefore necessary to mix wheat flour with banana flour in order to get proper volume and crumb. LeClerc and Wessling³⁴³ carried out experiments using 25% banana flour or powder and 75% standard wheat flour in the baking of bread (Table 44). The texture and color of the bread obtained was somewhat inferior to that made from wheat flour alone. It will be noticed from the table that these investigators used the factor 6.25 for converting nitrogen to protein. This factor is generally taken as 5.7 in the case of wheat products, and if this value had been used in

³⁴¹ H. W. von Loesecke, *Drying and Dehydration of Foods*. Reinhold, New York, 1943.

³⁴² Anon., *Tropenpflanzer*, 14, 265 (1910).

³⁴³ J. A. LeClerc and H. L. Wessling, *U. S. Dept. Agr. Bull.*, No. 701 (1918).

their calculations the protein content of the bread made from wheat flour would have been 7.97% instead of 8.74%. The protein content of such a bread would not, therefore, be greatly different from that of the bread containing banana flour, assuming that the factor 6.25 is used for the bread containing the banana flour.

TABLE 44. ANALYSES OF BREAD MADE WITH BANANA FLOUR AND STANDARD WHEAT FLOUR³⁴³

Type ^a	Total ash, %	Salt-free ash, %	Fat, %	Fiber, %	Protein (N×6.25), %	Carbo-hydrates, %	Color	Texture, % ^b
Unripe	1.78	0.71	1.40	0.28	7.33	54.21	Gray-brown	96
Ripe	1.65	0.76	1.20	0.29	7.49	54.37	Light gray	88
Spring wheat	1.28	0.31	2.08	0.13	8.74	52.77	Creamy	99

^a Breads with banana flour or powder contained 75% standard wheat flour.

^b Standard = 100.

Winckel³⁴⁴ advocates using 25% wheat flour and 75% banana flour from unripe fruit in making bread. In view of the results of LeClerc and Wessling, it is doubtful that a product acceptable to the American public could be obtained by such a combination.

The microscopic appearance of banana flour is of interest for identification purposes, and has been described by Ullan,³⁴⁵ Müller,³⁴⁶ Collin,³⁴⁷ and Hanausek.³⁴⁸

Both banana flour and powder should be stored in moisture-vapor proof containers. During storage there may be browning, caking, and off-flavor development. The material is also prone to attack by weevils. In this connection, Vilardebo^{348a} made a comprehensive study of the insects attacking dried bananas obtained from the African coast. He identified *Carpophilus hemipterus* L., *Carthartus quadricollis* Guer. (square-necked grain beetle), *Oryzaephilus surinamensis* L. (saw-toothed grain beetle), *Laemophloeus ferrugineus* Steph., and *Sitophilus oryzae* L. (rice or black weevil).

³⁴⁴ M. Winckel, *Chem.-Ztg.*, 48, 1778 (1924).

³⁴⁵ E. A. Ullan, *Quim. e. ind.*, 3, 216 (1926).

³⁴⁶ R. Müller, *Mitt. Lebensm. Hyg.*, 34, 229 (1943).

³⁴⁷ E. Collin, *Ann. fals.*, 8, 280 (1915).

³⁴⁸ T. F. Hanausek, *Z. Untersuch. Lebensm.*, 20, 215 (1910).

^{348a} A. Vilardebo, *Fruits d'Outre-Mer*, 1, 400 (1946).

Pearce,³⁴⁹ in his study on fluorescence development in various food products, found that fluorescing material in banana powder increased during storage, and that the rate of increase in such substances was more rapid as the storage temperature increased. Fluorescence increase was accompanied by a noticeable browning of the stored product. Pearce suggests that fluorescence increase might be used as a measure of quality of stored carbohydrate food-stuffs.

Dehydration of bananas does not significantly change the carbohydrate, fat, and protein values of the fruit, but the vitamin content, so far as ascorbic acid is concerned, is decreased. Thus, Harris and Poland³⁵⁰ found that spray-dried powder contained 0.051 mg. per gram of ascorbic acid, while drum-dried powder contained 0.063 mg. per gram. Assuming that the bananas used contained 0.100 mg. per gram of ascorbic acid, and that the fruit had a moisture content of 75%, the actual loss of ascorbic acid in spray drying was 87%, and in drum drying 84%. Gallot³⁵¹ reports an ascorbic acid content of 0.014 mg. per gram for dried bananas, but he does not state the kind, maturity, or method of drying.

B. Banana Figs

This product is prepared from the ripe fruit, and chiefly in the tropics. The American market for the figs is insignificant. The fruit is split longitudinally, and then each half may be cut across into three or more pieces about one inch in length. The fruit is then dried in the sun. The product thus obtained is usually dark in color with a leathery appearance. Yield of figs generally amounts to from 18 to 21%, based on the fresh fruit.³⁵²

A better appearing fig could probably be obtained by adequate sulfuring. In this connection, Savage and Arthur³⁵³ recommend subjecting the sliced fruit to 1.0 to 1.6% sulfur dioxide for 15

³⁴⁹ J. A. Pearce, *Can. J. Research*, F22, 87 (1944).

³⁵⁰ P. L. Harris and G. L. Poland, *Food Research*, 4, 317 (1939).

³⁵¹ S. Gallot, *Bull. soc. chim. biol.*, 22, 608 (1940).

³⁵² K. C. Jacob, *Madras Agr. J.*, 29, 217 (1945).

³⁵³ C. G. Savage and J. M. Arthur, *Agr. Gaz. N. S. Wales*, 46, 199 (1935).

minutes and then dehydrating at 120° to 125°F. (48.9° to 51.7°C.) for 18 hours. The dehydrated product is then placed in sweat boxes for from one to two weeks to equalize the moisture. A 3% solution of sulfurous acid could be used in place of sulfur dioxide, the sliced fruit would be dipped in the acid and then dehydrated at 150° to 160°F. (65.6° to 71.1°C.) for 8 to 10 hours.³⁵⁴ The finished product will contain about 130 p.p.m. of sulfur dioxide.

C. Confections

Various confections have been prepared from bananas. Such products as *Panchamruthan* and *Rasayanam* are known in India.³⁵⁵ The former is made by slicing banana pulp and adding such substances as treacle, honey, sugar candy, ghee, and raisins. Honey and ghee are added up to 10% by volume. The preparation of *Panchamruthan* is confined mainly to the Palmi Temple where the product is used as an offering to the Temple God. The annual production of this confection in India is said to amount to about 164,571 pounds. *Rasayanam* is made in Mysore State by cutting plantains into chunks over which is poured sugar and a small quantity of ghee. In the Travancore and Cochin States, the chunks are fried in oil and then coated with sugar.

D. Crystalline Bananas

A so-called crystalline banana has been prepared by cutting the fruit into thin slices and sprinkling with sugar crystals. The sugar penetrates the fruit and the center remains soft.³⁵⁶

Another type of confection conceived during World War II, and proposed for sale in the United States, was so-called "Banibs." This product was to be used as a substitute for raisins of which there was a shortage in this country. Banibs consisted of ground, dehydrated bananas, including the peel. To this was added about

³⁵⁴ H. W. von Loesecke, *Drying and Dehydration of Foods*. Reinhold, New York, 1943.

³⁵⁵ *Report on the Marketing of Bananas in India*. Central Agricultural Marketing Dept., Delhi, 1945.

³⁵⁶ Anon., *J. agr. trop.*, 12, 29 (1912).

10% sugar and a smaller amount of washed copra meal, the latter allegedly functioning as a stabilizer. The finished product was in the form of dark brown pellets about the size of raisins, and possessed a faint flavor suggestive of "cooked" bananas. There would probably be some question in the United States under the Food, Drug, and Cosmetic Act whether such a product could be sold without violating that Act. Inasmuch as the material contains banana peel, which the consuming public regards as inedible waste, and since it also contains inedible fibrous material from copra, the courts might rule that the product was adulterated within the meaning of the Act. Then, too, since the material was of such physical form and color as to suggest raisins, and with but a faint banana flavor, the consuming public might be led to believe that it was actually getting raisins, and it is quite possible that authorities would institute action under such provisions of the Act as would be found applicable. However, Banibs never saw the light of commercial markets.

E. Banana Coffee

This product has been made by dehydrating peeled, sliced fruit in a two-stage dehydrator. In the first stage, the fruit is partially dried at 120°F. (48.9°C.) for 9 hours; in the second stage final dehydration is carried out at 130°F. (54.4°C.) for 9 hours. The dehydrated product is then roasted and ground.³⁵³ McKenzie³⁵⁷ was granted a patent for the preparation of a banana coffee; the product could also be used as a breakfast cereal. It is difficult to see how products of this type would find a ready market.

F. Banana Chips

At one time banana chips were manufactured in the New York City area. The chips were prepared by frying plantain slices in deep fat in the same manner as potato chips. If the fruit contained significant amounts of invert sugar, the product was dark in color.

³⁵⁷ A. S. McKenzie, U. S. Pat. 994,178, June 6, 1911.

G. Banana Cocoa and Banana Chocolate

Winckel³⁵⁸ mentions the preparation of banana cocoa and banana chocolate, using banana flour as an ingredient. He does not go into details, but his product is no doubt merely a mixture of cocoa or chocolate with banana flour. About 20 years ago a similar product was marketed in certain areas of the United States, and consisted of a mixture of banana powder, cocoa or chocolate, dry whole milk, and malted milk. It was accepted by the public chiefly as a novelty, and sustained sales failed to be realized.

Since bananas are rich in carbohydrates, their use as a raw material for *alcohol* production has been given considerable attention, especially in tropical countries when the fruit is readily available. Early papers by Muntz³⁵⁹ and by Corenwinder³⁶⁰ describe the preparation of banana alcohol. Nagel³⁶¹ used a mash of banana flour and malt extract and obtained a yield of from 42 to 47.2 liters of "pure" alcohol per 100 kg. of flour. DeLapersonni³⁶² utilized a sterilized mash of ripe bananas, using a culture obtained from fermented cacao. With a green banana mash he used a *Mucor* in symbiosis with a yeast as his culture. Peratti and Riviera³⁶³ found it practically impossible to prepare alcohol from banana must without the addition of sugar. This is hard to understand considering the high fermentable carbohydrate content of the fruit.

The feasibility of preparing alcohol from bananas may be questioned under normal world economic conditions. Taking Nagel's yield figures as what might be expected, he obtained from 11.1 to 12.5 gallons of "pure" (which it will be assumed means 200-proof) alcohol from 220 pounds of banana flour. An equivalent amount of blackstrap molasses would yield slightly less than 7 gallons of 200 proof alcohol. Although the yield from banana flour is greater than what would be expected from blackstrap (if Nagel's yield data are accepted) the price differential between banana flour

³⁵⁸ M. Winckel, *Chem.-Ztg.*, 48, 178 (1924).

³⁵⁹ A. Muntz, *Compt. rend.*, 88, 156 (1879).

³⁶⁰ M. B. Corenwinder, *ibid.*, 88, 293 (1879).

³⁶¹ C. Nagel, *Z. spiritusind.*, 35, 185 (1912).

³⁶² E. L. DeLapersonni, *Bull. assoc. chim. suc. dist.*, 48, 28 (1931).

³⁶³ R. Peratti and V. Riviera, *Staz. agrar. ital.*, 50, 433 (1917).

and blackstrap under normal economic conditions would be too great to compensate for the increased yield in the case of banana flour.

H. Bananas in Preparation of Yeast and in Brewing

Fawcett³⁶⁴ mentions the successful use of bananas in the preparation of yeast and in brewing. In the latter instance, satisfactory results were obtained when 20% of the malt was replaced by banana flour. Nagel,³⁶¹ using a wort prepared by mashing unripe banana meal with 30% kilned malt, obtained a yeast crop of good quality and amounting to 20% of the weight of the ingredients mashed.

I. Banana Wine and Vinegar

Winckel³⁶⁵ states that he prepared a satisfactory *wine* from ripe bananas. Reynolds,³⁶⁶ Fawcett,³⁶⁴ and others³⁶⁷ mention the preparation of such a beverage by the African natives.

Banana vinegar has been prepared from a mash consisting of the pulp and peel of the ripe fruit.³⁶⁸ The mash was pasteurized and then inoculated with a pure culture of *Saccharomyces ellipsoideus*. Fermentation was allowed to proceed at 68° to 73°F. (20° to 23°C.) for from 14 to 20 days. The alcohol content of the mash amounted to from 6.55 to 10.12%. The "cider" thus

TABLE 45. ANALYSIS OF BANANA VINEGAR³⁶⁸

Specific gravity	1.0017-1.0223
Total acid as acetic, g./100 cc.	4.05-7.09
Fixed acid as sulfuric, g./100 cc.	0.02-0.87
Alcohol, by volume, %	0.13-0.46
Total solids, g./100 cc.	2.27-3.96
Total ash, g./100 cc.	0.89-1.18
Reducing matter (after inversion), g./100 cc.	Trace-0.10

³⁶⁴ W. Fawcett, *The Banana. Its Culture, Distribution and Commercial Uses*. Duckworth, London, 1921.

³⁶⁵ M. Winckel, *Chem.-Ztg.*, 48, 178 (1924).

³⁶⁶ P. K. Reynolds, *The Banana*. Houghton Mifflin, Boston, 1927.

³⁶⁷ A. Muntz, *Compt. rend.*, 88, 156 (1879).

³⁶⁸ H. W. von Loesেকে, *Ind. Eng. Chem.*, 21, 175 (1929).

obtained was filtered and subjected to acetification giving a yield of vinegar of from 48 to 53%, based on the weight of the fruit taken. Freise³⁶⁹ prepared a banana vinegar using a technique similar to that described above, with the exception that he diluted his mash with water prior to fermentation. Eggebrecht³⁷⁰ also diluted his mash with water, and after fermentation the mash was filtered through a Seitz filter and then distilled. The distillate was then permitted to undergo acetic fermentation. The product thus obtained is a distilled vinegar, and Eggebrecht claimed that his vinegar had an aroma similar to fresh bananas.

Ramirez³⁷¹ points out the possibilities of making banana vinegar and other fruit vinegars from commodities important in the economy of Puerto Rico.

J. Banana Pectin

This has been obtained on a laboratory scale from the peel of the fruit.³⁷² The ground peel was extracted with an equal weight of 0.2% citric acid for one hour at 208° to 212°F. (98° to 100°C.). The extracted material was filtered and the residue was again extracted with a fresh portion of citric acid solution. The cloudy extracts were combined and treated with a pure culture of *Aspergillus oryzae* and incubated at 98.6°F. (37°C.) for from three to four days to remove the starch. The material was then concentrated *in vacuo* and dried at 122°F. (50°C.). The finished product was a dark brown hygroscopic substance, whose approximate composition is indicated in Table 46. The analyses show that the pectin obtained by this method is quite impure, as indicated by the high ash and acid contents. This fact has also been pointed out by Ripa³⁷³ who makes a critical analysis of the data. Referring to Table 46, the methoxy number is a measure of the CH₃O group and formerly was thought to be a measure of the gelling power of a pectin. But it is now known that the jelling power of a pectin may be completely destroyed without an appreciable change in its

³⁶⁹ F. W. Freise, *Deut. Essigind.*, 36, 2 (1931).

³⁷⁰ H. Eggebrecht, *ibid.*, 43, 145 (1939).

³⁷¹ J. H. Ramirez, *Rev. agr. ind. com. Puerto Rico*, 35, 179 (1944).

³⁷² H. W. von Loesecke, *Fruit Products J.* (Feb., 1929).

³⁷³ R. Ripa, *Die Pektinstoffe*. Serger & Hempel, Braunschweig, 1937.

methoxy content. Measurements of pH of the pectin were made on a slurry of the material.

TABLE 46. ANALYSIS OF BANANA PECTIN³⁷²

Analysis	Sample		
	1	2	3
Total solids, %	91.95	92.59	93.09
Total ash, %	22.23	19.87	1.88
Pectin (as calcium pectate), %	10.19	11.54	25.79
Alcohol precipitate, %	9.07	—	—
Total acid (as citric), %	15.07	12.81	1.85 ^a
Starch, %	None	Trace	Present
Reducing sugars, %	Trace	—	Trace
Protein (N $\times$ 6.25), %	7.09	4.75	6.65
Methoxy No.	1.2	7.4	2.1
pH	4.7	4.5	3.5

^a As malic acid.

K. Canning

Little work has been done on the canning of bananas. This has probably been due chiefly to the fact that under normal conditions the fruit is available the year around, and there is little need for a canned product. On the other hand, there are sections of the United States, and certainly in other parts of the world, where the fresh fruit is not readily available. Another problem facing the investigator is the high pH of the fruit which would necessitate processing under pressure, unless the pH were altered by the addition of acid or acid fruit juices. Processing under pressure would not only ruin the flavor, but also significantly alter the texture. Even processing at atmospheric pressures will change the flavor, and the product has a cooked taste. Probably a satisfactory pack could be obtained as a combination of banana slices in citrus juices, such as tangerine, orange, lime, lemon, and grapefruit. It may also be possible to can a salad mixture of sliced bananas and grapefruit sections, with or without tangerine sections or orange sections. Orange and tangerine sections alone do not make a satisfactory pack, but in combination with banana slices it may be possible to obtain better results.

L. Banana Jam

Several years ago, during the period of plentiful supply of the fruit, banana jam was prepared in considerable quantities. Most of the jam was shipped in bulk in wooden candy tubs. A commercial formula³⁷⁴ for this type of banana jam is:

200 pounds of sugar
10 gallons of water
12 ounces of cream of tartar

Boil to 230°F. (110°C.) and add: 2.5 gallons of lemon juice;
200 pounds of ripe banana pulp

Boil to 224°F. (106.7°C.).

Other acid fruits, such as cranberries and pineapples, were at times substituted for lemon juice.

M. Bananas for Cattle Feed

Winckel³⁷⁵ has suggested the use of banana peel for cattle feed. The peel must, however, be mixed with other feeds and it cannot be fed alone. A more recent paper by Grünwald³⁷⁶ points out the use of plantain peel for feed.

N. Freezing

Unlike many other fruits, bananas do not seem to be well adapted for preservation by freezing. The defrosted product becomes a soggy mass, rapidly darkens and there is a loss of flavor. Darkening and flavor loss are probably due to enzyme action which is apparent even during frozen storage.

Many attempts have been made, and are still being made, to produce commercially a satisfactory frozen banana. Partial success has rewarded these attempts, but only insofar as frozen bananas for the ice cream or bakery trades are concerned. In the light of our present knowledge, it is unlikely that frozen bananas will find use as a frozen fruit for home use.^{376a}

³⁷⁴ G. L. Poland, *Private communication*, United Fruit Company, New York.

³⁷⁵ M. Winkel, *Chem.-Ztg.*, 48, 178 (1924).

³⁷⁶ O. Grünwald, *La concha de platano verde como material forrajero*. Unidos, Caracas, 1945.

^{376a} G. L. Poland, *private communication*, United Fruit Company.

It has been found that darkening and loss of flavor in the frozen product can be retarded by the use of ascorbic acid in combination with citric acid, the latter probably changing the pH , rendering the enzymes inactive, and permitting the ascorbic acid to act as an antioxidant. Orange juice is also said to be effective in retarding undesirable changes.^{376b} Ascorbic acid alone is effective, but is more expensive. Sucrose, in combination with ascorbic and citric acids, is found helpful in retarding deteriorative changes. Storage life of the frozen product appears to be about two months.

As an example of the preparation of a frozen banana pulp for the ice cream and bakery trade, the following may be cited. The pulp is sliced into cans holding 46 pounds (20.6 kg.). To this quantity of pulp is added 8 ounces (226.8 g.) of a mixture consisting of 25 pounds (11.4 kg.) of sucrose, 12 ounces (340.2 g.) of ascorbic acid, and 20 ounces (567 g.) of citric acid. Over this is added 3.5 pounds (1.58 kg.) of sucrose and a sheet of paper. The lid is placed on the can and the pulp is then frozen.

Mixtures of citric and ascorbic acids are commercially available as antioxidants for the freezing of fruits that may darken after defrosting. Such mixtures may consist of 96% citric acid and 4% ascorbic acid.

TABLE 47. COMPOSITION OF SOME MISCELLANEOUS BANANA PRODUCTS

Product	Water, %	Protein, %	Total sugar, %	Reducing sugars, %	Sucrose, %	Starch, %	Ash, %
Marmalade ^a	22.02	0.48	75.48	62.45	11.77	0.68	0.48
"Solid" Marmalade ^a	15.73	0.14	0.88	85.40	43.20	Trace	0.69
Jelly ^a	45.21	0.47	54.50	47.28	6.86	Absent	0.45
Chocolate with banana flour ^b	3.36	5.81	24.93	4.80	20.13	13.77	1.59
Banacao Scipat ^b	3.23	2.81	56.96	1.17	55.79	24.77	2.08
Bananina Scipat ^b	5.67	2.75	4.96	3.34	1.62	75.60	2.53
Bananina Scipat ^b	5.91	2.75	3.93	2.84	1.09	76.50	2.38
Lactobanacao Scipat ^b (milk powder type)	4.36	10.39	56.35 ^c	—	—	16.27	3.47
Banacao Scipat ^b	1.78	1.87	51.90	1.12	50.78	33.19	1.99

^a G. Fabriani, *Quaderni Nutriz.*, 6, 209 (1939).

^b A. S. Carteni, S. Perrelli, and A. Piergrossi, *ibid.*, 4, 310 (1937).

^c Soluble carbohydrates as glucose.

^{376b} R. Holzker, *private communication*, Florida Frozen Foods, Inc., Haines City, Florida.

**NUTRITIVE VALUE IN HEALTH
AND DISEASE**

The value of the banana in the diet has been known for some time, and ancient Chinese writings ascribe marvelous healing and medicinal effects not only to the fruit itself, but also to the root, leaves, and flowers of the plant.³⁷⁷ Bogert³⁷⁸ has ably presented the modern concept of the nutritive value of the fruit in health and disease.

About 20% of the ripe fruit consists of sugar, and slightly more than 1% of starch. Myers and Rose³⁷⁹ and Pease and Rose³⁸⁰ state that banana carbohydrates are from 96 to 99.5% utilizable. These data refer to very ripe or cooked bananas where the sugar content was high, or where the starch had been altered by cooking. Dehusses and Terrier,³⁸¹ using white mice, found that banana starch was 54% digestible; in a later paper Terrier and Dehusses,³⁸² using guinea pigs, showed that the starch of the fruit had an average digestibility of 79.58%. These data indicate that the starch in the fruit is less digestible than the sugars, and show why ripe fruit, which contains but little starch, is preferable to unripe fruit.

³⁷⁷ P. K. Reynolds in collaboration with C. Y. Fang, *Harvard J. Asiatic Studies*, 5, 165 (1940).

³⁷⁸ L. J. Bogert, *Dietary Uses of the Banana in Health and Disease*. United Fruit Co., Research Dept., New York, 1942.

³⁷⁹ V. C. Myers and A. R. Rose, *J. Am. Med. Assoc.*, 68, 1022 (1917).

³⁸⁰ M. C. Pease and A. R. Rose, *Am. J. Diseases Children*, 14, 379 (1917).

³⁸¹ J. Dehusses and J. Terrier, *Mitt. Lebensm. Hyg.*, 31, 259 (1940).

³⁸² J. Terrier and J. Dehusses, *ibid.*, 35, 8 (1944).

Although the protein content of the fruit is low, its digestibility is of interest. Rat feeding tests conducted by Eddy³⁸³ showed an average gain of 0.49 g. per day per gram of food eaten by the rats receiving banana protein, against 0.67 g. gain per day per gram of food consumed by rats receiving casein as a protein. In other tests in which banana protein constituted 18% of the diet, as compared with 18% casein, the rat growth was the same for both groups. Metabolism tests (using rats) showed that 64% of nitrogen was absorbed in the case of banana protein, against 92% for casein. It should be pointed out that the banana protein used was obtained by extracting the fruit with a salt solution and then coagulating the protein by heat. The protein fraction thus consisted of only albumin and globulin.

The banana is a fair source of calcium and iron, and contains copper, iodine, manganese, zinc, and cobalt³⁷⁸; it is quite rich in potassium, magnesium, sodium, and phosphorus. McCance and Widdowson³⁸⁴ have shown that both the iron and phosphorus in the fruit are 100% available. Hunscher *et al.*³⁸⁵ report that in experiments with children (5 to 8 years old) ingestion of bananas was accompanied by an increased retention, or an increased percentage of intake retained, of nitrogen, magnesium, calcium, sodium, phosphorus, chlorides, and sulfur.

The vitamin potency of bananas has already been discussed, and a comparison of the vitamin content of the fruit with other fruits and vegetables is given in Table 48.

Bananas are mildly laxative. Harris and Poland³⁸⁶ ascribe this effect to the free pectin and bound tannin in the ripe fruit. The indigestible residue, termed "crude fiber," is probably also a factor. Experiments by Shepard and co-workers³⁸⁷ indicate that

³⁸³ W. H. Eddy, *Nutritive Value of the Banana*. Teachers College, Columbia Univ., New York, 1933.

³⁸⁴ R. A. McCance and E. M. Widdowson, *The Chemical Composition of Foods*. Chemical Pub. Co., New York, 1940.

³⁸⁵ H. A. Hunscher, F. C. Hummel, and I. C. Macy, *Am. J. Diseases Children*, 60, 509 (1940).

³⁸⁶ P. L. Harris and G. L. Poland, *J. Lab. Clin. Med.*, 24, 580 (1939).

³⁸⁷ M. L. Shepard, F. C. Hummel, and I. C. Macy, *Am. J. Digestive Diseases Nutrition*, 7, 248 (1940).

variations in the disappearance of fiber from the alimentary tract are more closely related to the proportions of lignin, cellulose, and hemicellulose than to the total intake of fiber. As already pointed out, lignin forms a major part of the so-called "crude fiber" of bananas. The distribution of lignin, cellulose, and hemicelluloses may affect the utilization of foodstuffs, as well as the bulk and consistency of the stool. However, Jacquot³⁸⁸ points out that chemically pure cellulose does not appreciably affect the coefficient of digestive utilization of digestible foods.

TABLE 48. VITAMIN CONTENT OF BANANAS AS COMPARED WITH OTHER FRUITS AND VEGETABLES^a

Commodity	Vitamin content (per 100 g. fresh edible portion)			
	Vitamin A (carotene), I.U.	Thiamine, μg.	Riboflavin, μg.	Ascorbic acid, μg.
Bananas	50-332	42-62	87-88	3-11
Apples	75	25	73	5-8
Oranges	62-286	78	32-45	52-72.5
Grapefruit	0	—	37-45	27-45
Tangerines	932	84	58	41.9
Pears	10	25	76	3-5
Carrots	2100	72	66	3-5
Cabbage	0-100	81	44	50-90
Tomatoes	1000	78	52	21-24
Cantaloupe	300	60	73	26-34
Peaches	1700	20	64	8

^a The figures should be taken as comparative and not necessarily as absolute.

Another factor contributing to the laxative effect of the fruit is probably the change in intestinal flora brought about by the consumption of a sufficient quantity of bananas. Eddy,³⁸⁹ for example, found that the sugars in bananas have a definite action on intestinal flora in that they tend to increase the Gram positive or acidic groups and to decrease the Gram negative organisms.

³⁸⁸ R. Jacquot, *Chimie & industrie*, 55, 424 (1946).

³⁸⁹ W. H. Eddy, *Nutritive Value of the Banana*. Teachers College, Columbia Univ., New York, 1933.

Weinstein and Weiss³⁹⁰ report that the feeding of bananas resulted in a predominance of the acidophilus bacillus in the feces within two weeks, but that the effect was not permanent.

About 23 years ago the feeding of ripe bananas to infants, particularly to those suffering with celiac disease,* was an unheard of procedure. But in 1924 Haas³⁹¹ found that carbohydrates in the form of ripe bananas appeared to be tolerated perfectly in celiac disease conditions, making it possible to bring about a clinical cure in practically all cases he treated. Whether there was a factor in bananas other than the carbohydrate content which resulted in this cure was unknown to Haas. Experiments by other workers, particularly by Badenoch and Morris³⁹² have shed considerable light on the reason why banana sugars are well utilized in celiac disease, when other carbohydrates are not well tolerated. According to these workers, the sugars in the fruit have the ability to raise the blood sugar to normal heights in children with celiac disease, and this may be due to the resistance to fermentation in the intestinal tract. MacLean and Sullivan³⁹³ postulate that there is a more normal metabolism of invert sugar. Other workers have suggested the utilization of banana carbohydrate as due to the softness of banana fiber, the bulky residue produced by pectins, the alkalizing action of the fruit upon the intestinal contents, and the slowness with which the carbohydrates are given up.³⁹⁴

Haas' first observations were quickly confirmed by Kerley and Craig,³⁹⁵ and since that time bananas have been successfully used in the treatment of celiac disease as evidenced by numerous case reports from all parts of the world.

From the time that Haas demonstrated the value of the banana in the treatment of celiac disease, the fruit has been accepted

* Celiac disease is a nutritional disturbance of late infancy and early childhood, due to the inability to utilize fats and carbohydrates in a normal manner.

³⁹⁰ L. Weinstein and J. E. Weiss, *J. Infectious Diseases*, 60, 1 (1937).

³⁹¹ S. V. Haas, *Am. J. Diseases Children*, 28, 421 (1924).

³⁹² E. Badenoch and N. Morris, *Quart. J. Med.*, 5, 227 (1936).

³⁹³ A. B. MacLean and R. C. Sullivan, *Am. J. Diseases Children*, 38, 16 (1929).

³⁹⁴ L. J. Bogert, *Dietary Uses of the Banana in Health and Disease*. United Fruit Co., Research Dept., New York, 1942.

³⁹⁵ C. G. Kerley and H. Craig, *Am. J. Diseases Children*, 28, 520 (1924).

as a constituent of the diet of normal infants. Bogert³⁹⁴ reports that the giving of bananas as the first solid food of all infants entering the New York Foundling Hospital was made routine practice about 1931. The fruit may be given as the sieved pulp, as such, or added to the milk formula. More recent work in this field has been reported by Lavastida.³⁹⁶

The use of bananas in malnourished or marasmic infants has been set forth by Thursfield,³⁹⁷ Benobel,³⁹⁸ Johnston,³⁹⁹ Craig,⁴⁰⁰ Day,⁴⁰¹ McNamara,⁴⁰² and others.

Although bananas are a source of ascorbic acid and have been successfully used in antiscorbutic diets, an adequate intake of the fruit as the sole source of this vitamin would necessitate the consumption of too great a bulk. Bogert³⁹⁴ suggests some more concentrated source of this vitamin, such as citrus fruits or tomato juice, as a supplement to bananas in order to assure an adequate daily quota of ascorbic acid.

The banana as a valuable constituent of the diet of normal children has been demonstrated by more recent work of Macy and her co-workers.⁴⁰³ The fruit had the ability to supplement the regular diet and to produce increased growth in children, and to stimulate increased retention of mineral elements.

The inclusion of the raw fruit in the diet to aid in combating diarrhea was apparently pioneered by such European pediatricians as Fanconi,⁴⁰⁴ Moro,⁴⁰⁵ and Heisler.⁴⁰⁶ It is probable that the

³⁹⁶ R. la Portilla y Lavastida, *Bol. soc. cubana pediat.*, 15, 1025 (1943).

³⁹⁷ H. Thursfield, *Arch. Disease Childhood*, 2, 49 (1927).

³⁹⁸ S. Benobel, *Lisboa Med.*, 10, 691 (1933).

³⁹⁹ J. A. Johnston, *J. Am. Dietet. Assoc.*, 3, 93 (1927).

⁴⁰⁰ J. D. Craig, *J. Pediatrics*, 13, 239 (1938).

⁴⁰¹ H. F. Day, *J. Nat. Ed. Assoc.*, 17, 169 (1928).

⁴⁰² J. J. McNamara, *Am. J. Public Health*, 19, 605 (1929).

⁴⁰³ I. C. Macy, F. C. Hummel, H. A. Hunscher, M. L. Shepard, and H. J. Sonders, *J. Nutrition*, 19, 461 (1940).

⁴⁰⁴ G. Fanconi, *Acta Paediatrica*, 11, 380 (1930).

⁴⁰⁵ E. Moro, *Klin. Wochschr.*, 8, 2414 (1929).

⁴⁰⁶ Heisler, *ibid.*, 9, 408 (1930).

mechanism of the action of bananas in such instances is closely related with the ability of the fruit to change the intestinal flora, as previously mentioned. This has been further substantiated by Kahn,⁴⁰⁷ and more recently by Joslin.⁴⁰⁸ The action on the intestinal bacteria is explained by absorption and mechanical removal of the organisms due chiefly to the pectins of the fruit; checking of their growth by change in the nutritive medium from one of low carbohydrate content to one of high carbohydrate content plus alkaline salts, and stimulation of intestinal secretions which increase bactericidal action.⁴⁰⁹

Of more recent interest in the treatment of diarrheal conditions is the report of Kantor⁴¹⁰ on the successful treatment of 40 cases of bacillary dysentery among soldiers. Ripe bananas were given a prominent place in the diet. The use of a banana diet in the treatment of other diarrheal diseases in the adult has been studied by Bethea and Bethea⁴¹¹ who indicate that the fruit is useful in the control of this condition in the adult as well as in the infant.

As previously mentioned, the banana is mildly laxative, and for this reason has been found useful in certain types of constipation.⁴¹²⁻⁴¹⁴ Bogert,⁴¹⁵ in this connection, describes the action of the fruit as that of "a normalizer of colonic functioning."

Bargen,⁴¹⁶ Voegtlin,⁴¹⁷ Weinstein and Bogin,⁴¹⁸ and Bethea and Bethea⁴¹¹ have indicated the value of the fruit in the diet of those suffering with colitis. While the case reports are not conclusive, Bogert⁴¹⁵ believes that bananas may be a promising dietary aid for the relief of acute symptoms, and for the promotion of

⁴⁰⁷ B. S. Kahn, *Arch. Pediat.*, 50, 330 (1933).

⁴⁰⁸ C. L. Joslin, *Southern Med. J.*, 29, 1007 (1936).

⁴⁰⁹ A. von Reuss, *Wien med. Wochschr.*, 88, 1023 (1938).

⁴¹⁰ J. L. Kantor, *Military Surgeon*, 88, 465 (1941).

⁴¹¹ O. W. Bethea and H. Bethea, *Intern. Med. Digest*, 32, 369 (1938).

⁴¹² E. E. Cornwall, *Med. Times Long Island Med. J.*, 62, 313 (1939).

⁴¹³ J. L. Kantor and L. F. Cooper, *Ann. Internal Med.*, 16, 965 (1937).

⁴¹⁴ L. F. Rettger, L. Weinstein, M. Bogin, and J. E. Weiss, *Am. J. Digestive Diseases Nutrition*, 5, 170 (1938).

⁴¹⁵ L. J. Bogert, *Dietary Uses of the Banana in Health and Disease*. United Fruit Co., Research Dept., New York, 1942.

⁴¹⁶ J. A. Bargen, *Am. J. Digestive Diseases Nutrition*, 1, 190 (1934).

⁴¹⁷ W. L. Voegtlin, *Northwest Med.*, 38, 252 (1939).

⁴¹⁸ L. Weinstein and M. Bogin, *Rev. Gastroenterol.*, 6, 21 (1939).

healing of intestinal lesions in chronic and acute ulcerative colitis.

Other diseases of the alimentary tract in which the banana has been found to be a valuable dietary adjunct are typhoid fever,^{419,420} and peptic ulcers.⁴²¹

As early as 1917, Chase and Rose⁴²² pointed out the usefulness of the fruit in cases of acute nephritis. Riaboff⁴²³ suggested the inclusion of bananas in the diet in cases of uremia.

Von Noorden⁴²⁴ first suggested the use of bananas in the dietary treatment of diabetes. He found that the urine sugar was not increased as great as when cereal carbohydrates were used. Higgins⁴²⁵ also reported a greater tolerance for banana carbohydrates than for those of cereal. Apparently there is a delayed absorption of banana carbohydrate, a fact noted by Pollack and Dolger,⁴²⁶ particularly in the case of bananas with cream. This fact is of importance in insulin therapy, and especially when protamine zinc insulin or other forms of insulin with delayed absorption and prolonged activity are used.

Bogert⁴²⁷ states that bananas are suitable for inclusion in the diet in conditions such as gout, hypertension, and cardiac diseases because the fruit is free from bodies that give rise to uric acid and easily provides digested nourishment in concentrated form. Bananas may be of specific aid in gouty conditions by increasing the uric acid solvent power of the urine.^{428,429}

⁴¹⁹ C. L. Joslin, *Southern Med. J.*, 29, 1007 (1936).

⁴²⁰ W. F. Schoffman, *J. Pediatrics*, 18, 399 (1941).

⁴²¹ J. M. Twigg, *New Zealand Med. J.*, 38, 188 (1939).

⁴²² A. F. Chase and A. R. Rose, *J. Am. Med. Assoc.*, 69, 440 (1917).

⁴²³ J. Riaboff, *Urol. and Cutaneous Rev.*, 40, 850 (1936).

⁴²⁴ C. von Noorden, *Med. Klin.*, 9, 2020 (1913).

⁴²⁵ H. L. Higgins, *Am. J. Diseases Children*, 46, 446 (1933).

⁴²⁶ H. Pollack and H. Dolger, *Ann. Internal Med.*, 12, 2010 (1939).

⁴²⁷ L. J. Bogert, *Dietary Uses of the Banana in Health and Disease*. United Fruit Co., Research Dept., New York, 1942.

⁴²⁸ N. R. Blatherwick, *Arch. Internal Med.*, 14, 409 (1914).

⁴²⁹ M. Hindhede, *Z. physik. diätet. Therap.*, 17, 593 (1913).

**DISEASES AND INSECT PESTS
OF BANANAS**

Mention has already been made of the diseases to which bananas may be subjected during transportation. In this chapter diseases and insects attacking the plant and the fruit will be discussed. Such diseased conditions will be mentioned only insofar as they affect the gross appearance of the fruit, or are a threat to the economy of the banana industry.

The diseases mentioned are not all of equal economic importance, and they should therefore be evaluated in proper perspective. Because of the present-day more efficient methods of transportation and handling, most diseases to which the fruit was prone in the early days of the industry are probably now of minor economic importance in the majority of banana-producing countries. As examples, squirter disease has been reported only in bananas originating in Queensland and is not of significance in other producing areas; a *Sclerotinia* rot of bananas has been considered of importance in Palestine, but as far as known has not been deemed of serious importance elsewhere.

Of the diseases of the plant, Panama disease and Sigatoka are perhaps the only maladies of significance and they have profoundly altered banana production.

A. Diseases of the Plant**1. PANAMA DISEASE**

Panama disease is one of the most important diseases affecting the banana plant. Many names have been applied to this malady

since it was first mentioned by Higgins⁴³⁰ in 1904 at Honolulu. In English-speaking countries, the disease has been called "banana blight," "banana wilt," "droop," "tired bananas," "the disease," and "banana disease." It has been known as "la enfermedad de planto," "la enfermedad," and "enfermadad Panama" in Spanish-speaking regions. The name "banana wilt" should not be confused with the bacterial wilt disease investigated by Wardlaw in Brazil, and which is sometimes given the name "banana wilt."

Panama disease shows a decided variation in its ability to attack different cultivated varieties of bananas, and unfortunately it most severely attacks those varieties most esteemed in any particular region. Curiously, varieties which are strongly attacked in one country appear to be resistant in another, although the disease is present in great abundance on some other variety. Considerable research has been undertaken in the effort to obtain disease-resistant varieties. The Lacatan has attracted serious attention as a possible substitute for the Gros Michel because the Lacatan is resistant to Panama disease.⁴³¹

The causative organism is *Fusarium oxysporum cubense*, first named by Smith,⁴³² and since then studied by Brandes,⁴³³ Reinking,⁴³⁴ Reinking and Wollenweber,⁴³⁵ Hansford,⁴³⁶ Wollenweber *et al.*,⁴³⁷ Wardlaw,⁴³⁸ and others.

A typical diseased plant first shows a yellowing of the lower or outer leaf blades and petioles. The change from green to yellow is usually sudden and startling. The leaves begin to wilt and within a day or two the fleshy leaf buckles at a point 3 or 4 inches from the pseudostem. The withered leaves brown, and finally the plant, weakened by disease, falls to the ground. The symptoms described may vary in different plantings. In some instances there is a dwarf-

⁴³⁰ J. E. Higgins, *Hawaiian Agr. Exp. Sta. Bull.*, 7 (1904).

⁴³¹ C. W. Wardlaw and L. P. McGuire, *Great Brit. Empire Marketing Board Report*, 36 (1931).

⁴³² E. F. Smith, *Science*, 31, 754 (1910).

⁴³³ E. W. Brandes, *Phytopathology*, 9, 339 (1919).

⁴³⁴ O. A. Reinking, *ibid.*, 16, 371 (1926).

⁴³⁵ O. A. Reinking and H. W. Wollenweber, *Philippine J. Sci.*, 32, 103 (1927).

⁴³⁶ C. G. Hansford, *Roy. Botan. Gardens Kew, Bull. Misc. Inform.*, 7, 257 (1926).

⁴³⁷ H. W. Wollenweber, C. D. Sherbakoff, O. A. Reinking, H. Johann, and A. A. Bailey, *J. Agr. Research*, 30, 833 (1925).

⁴³⁸ C. W. Wardlaw, *Tropical Agriculture Trinidad*, 6, 192 (1929).

ing or stunting of the entire plant, and the leaves on such plants do not wilt as rapidly as on larger plants.

If a bunch of fruit has formed on the attacked plant, the bunch will generally be found to be small, and development may be completely arrested after a few hands have formed. If the normal number of hands have already been formed, the individual fingers are small. The ovary is constricted at the calyx end giving the fruit the appearance of a "bottle neck." The fingers will not ripen uniformly, and occasional fingers may become rapidly yellow with a pithy flesh and a "starchy" taste. There are also well-marked changes in the internal tissues of the banana plant itself.

Control of the disease has been attempted by destroying infected plants, planting healthy stock, planting resistant varieties, and by sterilizing the soil. In connection with the latter, Meredith⁴³⁹ has shown that mercury compounds will kill *Fusarium oxysporum cubense* and prevent its spread. In field experiments he found that mercury compounds would stop the growth of the disease organism in the soil even after nine months of weathering. The banana plant itself was able to withstand higher concentrations of mercury compounds than the organism.⁴⁴⁰ Compounds used were ethyl mercury iodide, nitrophenolmercuric hydroxide, chlorophenolmercuric hydroxide, mercuric chloride, and mercurous chloride. Meredith's work was not concerned with the widespread application of this control method, and whether it is economically feasible must be decided by experiments on a much larger scale.

Another method of reclaiming land infested with Panama disease was noted by Wardlaw while in Honduras about 1941.^{440a} He observed that large areas of land infested with the disease were being flooded, a technique based on the fact that *F. oxysporum cubense* requires oxygen to live. Wardlaw later reported^{440b} that the areas originally flooded for 6, 12, and 18 months had been producing fruit for nearly 6 years with only scattered cases of the disease appearing after 10 to 18 months. This method of flooding would probably be of no value in acid soils.

⁴³⁹ C. H. Meredith, *Phytopathology*, 32, 182 (1942).

⁴⁴⁰ C. H. Meredith, *ibid.*, 33, 835 (1943).

^{440a} C. W. Wardlaw, *Nature*, 147, 313 (1941).

^{440b} C. W. Wardlaw, *ibid.*, 160, 405 (1947).

2. SIGATOKA DISEASE

This malady has become of significance and has profoundly altered banana production. In 1939 it was present in all major banana-producing regions of the Western Hemisphere. No large banana-producing country has escaped its ravages, and its control has modified the methods of fruit production.

The disease apparently first appeared in Fiji in 1913 on Gros Michel growing in the Sigatoka district (hence the name for the disease), and subsequently spread to other districts.⁴⁴¹ The history of the disease has been reviewed by Popenoe.⁴⁴² The sickness is caused by a specific organism, *Cercospora musae* Zimm., and was first described by Zimmerman.⁴⁴³ He isolated the organism from material received from Java. In 1914, Masee⁴⁴⁴ described the organism as found in Fiji. A recent paper by Leach⁴⁴⁵ demonstrates the presence of an ascigerous stage of *C. musae*, and which he has named *Mycosphaerella musicola*. Leach further discusses the possible importance of ascospore infection in the etiology of leaf-stop disease in the Gros Michel banana in Jamaica.

The economic effect of Sigatoka has been far-reaching. In 1925 it made serious inroads into Australia, then burst into Siam, China, India, and Malaysia devastating the banana plantations. In 1934 it penetrated the Western Hemisphere to strike Surinam and Trinidad, and in 1936 the banana areas of Honduras and Guatemala felt its destructive hand. Within one year the disease had infected 80% of the Honduras crop.⁴⁴⁶ Infections in Cuba, Mexico, Haiti, Jamaica, Costa Rica, Panama, and Colombia soon followed.

According to Wardlaw,⁴⁴⁷ the first indication of infection is the appearance of light brown-green indistinct linear markings from $\frac{1}{8}$ to $\frac{3}{8}$ of an inch long, lying parallel to the veins on the leaves. The spots subsequently increase slightly in size and dry out somewhat, forming dark, muddy brown to black linear-oblong or elliptic areas up to $\frac{1}{2}$ inch in length and about $\frac{1}{3}$ inch wide. When the spots remain small, little damage is done, but more frequently the

⁴⁴¹ C. W. Wardlaw, *Trop. Agr. (Trinidad)*, 11, 173 (1934).

⁴⁴² Wilson Popenoe, *J. Jamaica Agr. Soc.*, 43, 621 (1939).

⁴⁴³ A. Zimmerman, *Zentr. Bakt. Parasitenk., Abt. II*, 8, 219 (1902).

⁴⁴⁴ G. Masee, *Roy. Bot. Gardens Kew, Bull. Misc. Inform.*, 1914, 159.

⁴⁴⁵ R. Leach, *Trop. Agr. (Trinidad)*, 18, 91 (1941).

⁴⁴⁶ C. M. Wilson, *Country Gentleman*, 109, No. 9, 7 (1939).

⁴⁴⁷ C. W. Wardlaw, *Trop. Agr. (Trinidad)*, 11, 173 (1934).

tissue around the spots begins to die rapidly and enlarge. Coalescing, dead patches are formed so that the leaf is more or less completely destroyed. This rapid destruction renders the disease very serious.

The effect on the fruit is indirect. Mature bunches fall and fail to ripen. In bunches that are nearly mature, the flesh ripens, but externally the fingers remain undersized and more or less angular. Although the flavor of the fruit is normal, its small size tends to make it unmarketable.

As a control, dusting or spraying with Bordeaux mixture has been tried. Wardlaw⁴⁴⁷ states that this method did not meet with the desired success in Queensland. It is difficult to spray the broad leaves of the plant and make the liquid stick, and special high-pressure sprayers are necessary. To keep the disease under control, the plant must be sprayed at intervals of 10, 12, or 30 days, depending upon the virulence of the disease.⁴⁴⁸ Dusting by means of airplanes has also been tried.

Before World War II, many of the plantations in Honduras were equipped with pipeline spray systems centering about permanent Bordeaux mixing plants provided with Diesel pumps to force the mixture into pipe mains which distributed it into quadrangular grids of smaller pipes. The smaller pipes were fitted with hose spigots at 100- to 140-foot intervals. One spray plant could service from 800 to 1000 acres (Wilson⁴⁴⁶). Spray residue was removed by dipping the stems in dilute acid and then removing the acid with sprays of clean water.

As another means of control, Wardlaw⁴⁴⁷ recommends wider spacing of the plants, good cultivation, and sanitary measures such as removal and burning of infected leaves.

3. BLOOD SICKNESS

Blood sickness (*maladie du sang*, *Bloedziekte*) has been studied by Gaumann,⁴⁴⁹ who attributes the disease to a bacterium, *Pseudomonas celebensis* nov. sp., present in the ducts of the plant. The name of the disease is derived from the fact that infected fruit exudes a reddish mucus, when the peel becomes yellow.

⁴⁴⁸ H. Maness and R. Tucker, *World Banana Production and Trade*. U. S. Dept. Agr., Washington, D. C., April, 1946.

⁴⁴⁹ E. Gaumann, *Med. Inst. Pflanzenzicken*, No. 50, 1921; No. 59, 1923.

4. BUNCHY-TOP DISEASE

Bunchy-top disease is characterized by the tendency of the leaves of the plant to remain more or less erect resembling a sort of fan. The malady is also sometimes called "cabbage top." It is a virus disease, the plant louse *Pentalonia nigronervosa* being the agent of transmission. If the plant survives, it remains small, stunted, and fragile, while the extreme ends of the fingers of fruit formed become black.

B. Diseases of the Fruit

1. CIGAR END DISEASE

Cigar end disease is a storage disease caused by a fungus, *Stachyliidium theobromae* Turc.⁴⁵⁰ The infection originates in the perianth and spreads slowly backward over the fruit causing a tip rot that looks like ashes hanging to the end of a cigar. The internal symptoms differ from those of many storage diseases in that the pulp of the fruit does not become soft and watery, but acquires a dry, "fibery" appearance. Wardlaw⁴⁵⁰ describes the microscopic appearance of the infected fruit as follows. Toward the distal end of the finger, the epidermis is thrown into a large number of folds. The underlying cells are necrosed, brown in color, and have shrunken gummy contents and involute walls. The vascular strands also become affected and are found to be collapsed and undulating in outline. The epidermal cells become affected and their size is diminished, and they become separated from one another. The cuticle, too, is frequently observed to be thrown into numerous minute folds, one over the other.

Kervégant⁴⁵¹ states that in the Canary Islands the disease is combated by removing by hand the pistal and perianth of the flower as soon as the fruit starts to form. Simmonds⁴⁵² suggests opening the young plant to the air and light and at the same time removing the bracts protecting the hands. For additional information the recent paper by Brun and Merny should be consulted.^{452a}

⁴⁵⁰ C. W. Wardlaw, *Trop. Agr. (Trinidad)*, 7, 115 (1930).

⁴⁵¹ D. Kervégant, *Le Bananier et son Exploitation*. Marit et Colon, Paris, 1935.

⁴⁵² J. H. Simmonds, *Queensland Agr. J.*, 30, 438 (1928).

^{452a} J. Brun and G. Merny, *Fruits d' Outre Mer*, 2, 191 (1947).

2. BLACK TIP DISEASE

Black tip disease is caused by *Helminthosporium torulosum* (Syd.) Ashby. Kervégant⁴⁵¹ describes the symptoms as found in fruit grown in Bermuda, as follows. The extreme apex of the fruit becomes blackened commencing just above the perianth where the disease apparently originates. At the end of several weeks, the fruit becomes affected to a length of about 5 cm. Ogilvie⁴⁵³ has observed blackening for greater distances than this. The diseased zone is often of an irregular configuration, most developed on one of the sides of the finger, and is bounded by a gray or clear yellow edge. In an advanced stage, it is frequently cracked and appears desiccated, but the corrugations and wrinkles observed in cigar end disease are little marked in black tip disease. The pulp is only slightly attacked, and then only in the vicinity of the tip of the fruit. Ripening of the fruit appears to arrest the development of the lesion.

Improvement in the sanitation of culturing is suggested as a means of combating the disease. For instance, it has been found that diseased conditions are more prevalent in old plantations, and in those where the trees are not properly spaced.

3. BOTRYODIPLODIA FRUIT ROT

Botryodiplodia fruit rot is caused by *Botryodiplodia theobromae* Pat. Wardlaw⁴⁵⁴ believes this to be the same organism described by Sydow and Butler⁴⁵⁵ and named *Diplodia musae* by them. *B. theobromae* is a wound parasite, grows rapidly, and has considerable capacity for utilizing carbohydrates even when present in high concentrations.

The disease may be important in bananas in storage and is not only responsible for a downward rotting of the main stalk of the whole bunch, but it also causes finger dropping, fruit spots, and blemishes, and an extensive tip rot. The fruit is rapidly exploited by the fungus, the flesh becomes soft or even semiliquid with a sweetish odor. These symptoms are caused by absorption of the cell contents by the fungus. The skin becomes dark in color,

⁴⁵³ L. Ogilvie, *Phytopathology*, 18, 531 (1928).

⁴⁵⁴ C. W. Wardlaw, *Trop. Agr. (Trinidad)*, 7, 115 (1930).

⁴⁵⁵ H. Sydow, P. Sydow, and E. J. Butler, *Ann. Mycol.*, 14, 177 (1916).

wrinkled, and covered with a crust of small, black pycnidia. The mold hyphae penetrate chiefly through the middle lamellae, but they can also pass freely from cell to cell.

Growth of the fungus can be controlled by rapid cooling of the fruit to 53°F. (11.7°C.) after harvesting.

4. BANANA FRECKLE

Banana freckle (black spot) is caused by *Macrophoma musae* Berl. and Vogl. The disease is characterized by reddish black spots on the peel of the fruits as they approach complete maturity. Most commercial varieties may be attacked; the Gros Michel is very resistant. As a control measure, Pope⁴⁵⁶ recommends spraying with Bordeaux mixture and wrapping the fruit, before it has fully developed, in newspaper or special strong paper made for the purpose. The top of the bunch must be covered by the paper.

5. PITTING DISEASE

Pitting disease was one of the principal sources of wastage in Brazilian bananas about 15 years ago.⁴⁵⁷ Tomkins⁴⁵⁸ isolated a species of *Pestalozzia* from typical pits or spots, but he was unable to reproduce the disease in inoculation experiments. Wardlaw and McGuire⁴⁵⁹ isolated a white fungus—which they identified as *Piricularia grisea* (Cke.) Sacc.—as the causative agent in the production of pitting disease.

The disease remains localized in its primary stage. Although the spots are small in diameter, there is a deep invasion of the underlying tissues. This brings about a secondary infection in the case of finger stalk infections, and leads to finger dropping. Thus attack by *P. grisea* is quickly followed by other fungi such as *Gloeosporium musarum* and *Fusarium* Spp. Since the disease is of plantation origin, Wardlaw and McGuire⁴⁵⁷ suggest weekly or fortnightly inspection of the fruit on the tree, and cutting off transition leaves at the crown of the plant as means of combating the disease. The cutting should be done with a sharp knife to avoid

⁴⁵⁶ W. T. Pope, *Hawaiian Agr. Expt. Sta. Bull.* No. 55, 1926.

⁴⁵⁷ C. W. Wardlaw and L. P. McGuire, *Trop. Agr. (Trinidad)*, 9, 193 (1932)

⁴⁵⁸ R. G. Tomkins, *ibid.*, 8, 255 (1931).

⁴⁵⁹ C. W. Wardlaw and L. P. McGuire, *ibid.*, 10, 255 (1933).

injuring the main stalk. The bracts that protect the hands should be carefully removed, and the bunch protected from sun scorch.

6. BLACK FINGER-TIP DISEASE

Black finger-tip disease bears a close resemblance to black tip disease at certain stages. Black finger-tip disease is of only occasional occurrence. Wardlaw and McGuire⁴⁶⁰ observed the malady in Brazil and attributed it to sun-scorched finger tips followed by the invasion of a species of *Fusarium*. In the early stages, sun-scorching causes a pale greenish yellow color to appear at the finger tips, chiefly on the lower side. A fungus infection soon follows and fungal penetration leads to a blackening of the scalded tissue. As the damaged area increases in size, fissuring often takes place. When a number of fingers have become infected, the bunch becomes unsightly and useless for marketing.

7. ANTHRACNOSE

Anthracnose is found in all countries where bananas are cultivated, and is caused by the cosmopolite fungus, *Gloeosporium musarum* Cooke and Massee. The fungus will attack fruits other than bananas. The condition has been studied by Taro,⁴⁶¹ Wardlaw,⁴⁶² Ashby,⁴⁶³ Delacroix,⁴⁶⁴ and others. The fruit may be attacked on the plantation, but more frequently after harvesting, in the course of transportation or when on sale at local markets. The diseased fruit shows small, round black specks. In advanced stages, the specks coalesce forming a large brown zone which in severe cases may cover the entire fruit. Groups of characteristic salmon-colored spores appear on the surface of the spots. Bananas so affected ripen prematurely and finally turn black and rot. The symptoms as outlined above will vary somewhat according to variety, but the disease is generally first noticeable when the fruit begins to turn yellow.

Kervégant⁴⁶⁵ states that the diastatic enzymes secreted by

⁴⁶⁰ C. W. Wardlaw and L. P. McGuire, *ibid.*, 9, 193 (1932).

⁴⁶¹ R. G. Taro, *J. Dept. Agr. Porto Rico*, 6, 1922.

⁴⁶² C. W. Wardlaw, *Trop. Agr. (Trinidad)*, 8, 327 (1931).

⁴⁶³ S. F. Ashby, *ibid.*, 8, 322 (1931).

⁴⁶⁴ G. Delacroix, *Agr. prat. Pays Chauds*, 2, 762 (1902-03).

⁴⁶⁵ D. Kervégant, *Le Bananier et son Exploitation*. Marit et Colon, Paris, 1935.

Gloeosporium do not attack the starch granules, or at least their action on the starch is insignificant. This explains in part why the fungus attacks fruit on the verge of maturity when the most sugar is present, and why varieties of fruit high in sugar are the most susceptible to attack.

Anthracnose may be combated by handling the fruit in such a manner as to discourage bruising. The fruit is placed in well-ventilated ripening rooms, at not too high relative humidity, and at a temperature of from 51.8° to 53.6°F. (11° to 12°C.). The bananas should be quickly cooled from tropical temperatures after harvesting, and then ripened as rapidly as possible, using ethylene if necessary.⁴⁶⁶

8. THIELAVIOPSIS FRUIT ROT

Thielaviopsis fruit rot has been studied by Wardlaw and McGuire⁴⁶⁷ and by Tomkins.⁴⁶⁸ The condition is caused by the fungus *Thielaviopsis paradoxa*. It is a wound parasite and does not invade intact tissue. The peel of infected fruit presents an irregular black coloration, and, at the same time, the pulp becomes soft and deep brown in color. Once the stalk is attacked, the fruit can no longer sustain itself and therefore falls. Fruit may become infected in the field, or in the hold of ships previously carrying infected fruit.

9. LASIODIPLODIA FRUIT ROT

Lasioidiplodia fruit rot is caused by *Lasioidiplodia theobromae* (Pat.) Griff and Maubl. It is a wound parasite and well organized in the tropics, and may cause a general decay of the stalk and fingers. When the fingers are attacked, the disease starts at the level or immediately below the perianth and then spreads uniformly along the fruit. The peel assumes a dark color and becomes soft and wrinkled, while the pulp becomes mushy and finally semi liquid. The decay, which is accentuated at the approach of maturity, may affect two thirds, or even all, the fingers. At high relative humidities

⁴⁶⁶ C. W. Wardlaw and L. P. McGuire, *Great Brit. Empire Marketing Board Report*, 36 (1931).

⁴⁶⁷ C. W. Wardlaw and L. P. McGuire, *Trop. Agr. (Trinidad)*, 10, 255 (1933).

⁴⁶⁸ R. G. Tomkins, *ibid.*, 8, 255 (1931).

and high temperatures, the fungus may run rampant on the surface of the peel forming a gray, feltlike mat from 0.5 to 1.0 cm. thick.

Microscopically, the first invasion of the fungus is noticed in the intercellular spaces of the subdermal tissues. The cellular walls are not destroyed. The intercellular mycelia shoot out slender threads which penetrate the cells and absorb the contents. The tissues are overrun by mycelia of large diameter and dark brown in color in the advanced stage of infection. As the cells are drained of their contents, there is a general contraction of the tissues accompanied by characteristic folding or wrinkling of the peel. The pulp is completely disintegrated and rendered semiliquid.⁴⁶⁹

In the vicinity of the stomata where the intercellular spaces are more developed, pycnides form which give the peel a leathery appearance. These pycnides, rounded or bottle-shaped, are separated or are run together and are either superficial or lightly sunk in the tissues.⁴⁶⁹

There appears to be considerable evidence that the fungus can easily assimilate carbohydrates, and are capable of developing in the presence of concentrated solutions of starch and sugar. This property, along with the fungus' singular capacity for penetration, explains why it is a parasite of considerable danger during transportation of the fruit. Present-day improved methods of shipping have done much to remove serious damage by this fungus.

10. SQUIRTER DISEASE

Squirter disease has been investigated by MacLennan and Hoëtte,⁴⁷⁰ who state that the malady is caused by *Nigrospora musae* nov. sp. Simmonds,⁴⁷¹ and more recently the Department of Agriculture of New South Wales,⁴⁷² have also studied the disease. The latter investigator has named the fungus *Nigrospora sphaerica*. The disease is not apparent before the bananas are put into the ripening rooms. They appear sound externally; only in severe cases does the peel have a characteristic blue-black color-

⁴⁶⁹ D. Kervégant, *Le Bananier et son Exploitation*. Marit et Colon, Paris, 1935.

⁴⁷⁰ E. J. MacLennan and S. Hoëtte, *Council Sci. Ind. Res. Australia*, Bull., No. 75, 1933.

⁴⁷¹ J. H. Simmonds, *Queensland Agr. J.*, 40, 98 (1933).

⁴⁷² Anon., *Agr. Gaz. N. S. Wales*, 57, 179 (1946).

tion. However, the pulp beneath the peel is decomposed, brown, and semiliquid. If the fruit is squeezed, the pulp gushes out of the peduncle or at the side. It is probably this phenomenon that gives the malady its name. Decay starts in the central region, generally at the side of the peduncle, and extends at varying distances in the direction of the point.

According to MacLennan and Hoëtte and to Simmonds, development of the mold is stopped by temperatures higher than 89.6°F. (32°C.) and growth is at its maximum at temperatures of 71.6° to 77°F. (22° to 25°C.). Thus the disease is encountered mostly during the cool months in banana-producing countries. It is liable to develop in chilled fruit that must be held at ripening temperatures for a long period of time. The disease is not of serious economic importance, and has been reported only in bananas originating in Queensland. There the fruit is dipped in a solution of salicylanilide in an attempt to control the disease.

11. OTHER DISEASES

A rot of bananas in Palestine due to *Sclerotinia sclerotiorum* has been described by Reichert and Hellinger.⁴⁷³ The disease starts at the tip of the banana. The pulp shows a reddish coloration changing to a reddish black and then black. This is particularly noticeable at the center of the pulp. A hardening appears in the interior and surface of the fruit. Infection spreads rapidly from one fruit to another by simple contact. The parasite requires a fairly high temperature for development.

Kervégant,⁴⁷⁴ quoting Johnston, describes a *banana fruit spot disease* that may be prevalent at certain seasons of the year in the Caribbean banana areas. The sickness is characterized by small round spots, generally black in color. There are apparently three types of spots: one appearing on the plantation on young fruit and persisting up to maturity, another affecting 3/4 full fruit and continuing to progress after harvesting, and the third developing on the green fruit or "turning fruit," which is maintained in an unfavorable condition during ripening. Fruit of inferior quality

⁴⁷³ L. Reichert and E. Hellinger, *Hadar*, 3, 190 (1930).

⁴⁷⁴ D. Kervégant, *Le Bananier et son Exploitation*. Marit et Colon, Paris, 1935.

is usually attacked, and the disease is prevalent during the autumn and winter months when the temperature and the evaporation rates are low.

C. Insect Pests

1. BANANA WEEVIL BORER

The banana weevil borer (*Sphenophorus sordidus*) may cause damage in certain banana-producing countries. It attacks the young suckers which quickly die. If the plant itself is attacked, at a later stage, it appears healthy and will produce a good bunch. The adult weevils are found in the soil about the roots and are often detected under dead leaves at the base of the stem. Recent work by Cuille⁴⁷⁵ should also be consulted in this connection.

According to Harris,^{475a} good results in the control of the borer have been obtained in the past in a number of Pacific Islands by establishing the beetle *Plaesius javanus*, a natural enemy of the borer. Introduction of this beetle into banana regions of East Africa was not, however, successful, for they failed to live. Another enemy of the borer is the beetle *Dactylosternum hydrophiloides*, introduced into Queensland in 1938. In 1941, Veitch^{475b} reported it as rapidly increasing.

2. BEETLE BORER

The beetle borer (*Fomarus bituberculatus*) damages the young banana bulbs in much the same manner as the weevil borer.

3. LEPIDOPTEROUS INSECT CAUSING "BANANA SCAB"

A lepidopterous insect causes a banana scab in Fijian fruit,⁴⁷⁶ rendering it unsightly. At first the fruit has minute longitudinal cracks on the incurved side, and later these cracks increase in number and run together. The whole of that portion of the fruit

⁴⁷⁵ J. Cuille, *Fruits d'Outre-Mer*, 1, 360, 372 (1946).

^{475a} W. F. Harris, *East African Agr. J.*, 13, No. 1, 15 (1947).

^{475b} R. Veitch, *Rept. of the Director of Plant Industry, Rept. Dept. Agr. Queensland*, 1940-1941.

⁴⁷⁶ W. Fawcett, *The Banana*. 2nd ed., Duckworth, London, 1921.

affected suffers a brown discoloration. The peel dries, and the fissures increase slightly in size. The cracks may extend to the pulp, which then starts to decay. The cracking is caused by the larvae of the small moth which eat away the peel.

4. FRUIT FLY

Tryon⁴⁷⁷ has described a fruit fly (*Dacus tryoni* Frogg.) that punctures the peel of green fruit before it has attained full size, and deposits its eggs beneath. The puncture is indicated by a small black spot which later widens to form a blotch of discoloration. The maggots burrow into the pulp which soon decays.

5. RUST THRIPS

The banana rust thrips (*Scirtothrips signipennis* Bagn.) probably causes greater losses than all of the foregoing insects put together.⁴⁷⁸ The pest is now established in most banana-growing districts of Queensland, for example, and there were major outbreaks in 1923–1925 and 1930–1933 causing widespread losses.⁴⁷⁹ In 1945 the rust thrips was again active in southern Queensland.⁴⁸⁰

The species was definitely determined by Tryon⁴⁸¹ in 1901, but rust was known to be a cause of loss to banana growers as far back as 1897. When the thrips is prevalent, growers may discard as much as 20 to 25 % of their fruit as unmarketable.⁴⁷⁹

Girault⁴⁸² has made a comprehensive study of the life history and habits of the thrips during certain months of the years. The insect commonly lays its eggs in the soft tissues of the pseudostem and in the fruit. The site of deposit is usually unmarked, but in some cases minute round pustules are apparent. On emergence from the egg, the larva pushes its way through the surface of the plant tissue and the point of exit is often seen as a very small cross slit. In addition, the amnion shed by the larva often remains as a "minute, hair-like, semi-prostrate, white thread." Pupation

⁴⁷⁷ H. Tryon, *Queensland Agr. J.*, 28, 360 (1912).

⁴⁷⁸ A. H. Slocum, *private communication*, United Fruit Co., Research Dept.

⁴⁷⁹ N. E. H. Caldwell, *The Control of Banana Rust Thrips*. Queensland Dept. Agr. and Stock, Div. Plant Ind. Research Bull., No. 16, 1938.

⁴⁸⁰ N. E. H. Caldwell, *Queensland Agr. J.*, 63, 83 (1946).

⁴⁸¹ H. Tryon, *Ann. Rept.*, *Queensland Agr. and Stock*, 1901–1924.

⁴⁸² A. A. Girault, *Queensland Agr. J.*, 29, 1 (1928).

takes place at shallow depths (usually less than 3 inches) in the soil. Both prepupae and pupae are able to crawl slowly because there is no pupal cell. After emerging from the pupal stage, generally in from 6 to 10 days, the adults probably make their way immediately to a nearby host.



Fig. 29. Injury caused by banana rust thrips.

The nature of banana rust itself, caused by the thrips, has been discussed at some length by Smith,⁴⁸³ and consists of a disfiguration of the peel of the fruit brought about by the feeding habits of *S. signipennis*. The fruit at first has a water-soaked appearance and is slightly reddish brown in color. Later there is a "smokiness," after which the red color of typical rust appears. This is apparently partly due to continued feeding by insects, and partly because of advancing maturity of the fruit. There is a disruption or cracking of the peel in some instances; the cracks generally run more or less longitudinally and are irregular in spacing and of variable length. The peel may split exposing the fruit pulp beneath.

⁴⁸³ J. H. Smith, *ibid.*, 40, 508 (1934); 41, 1 (1934).

As a means of control, Caldwell⁴⁸⁴ recommends bagging the bunches in 11 ounce hessian bags as soon as practical, and dusting with a nicotine dust fortnightly during the whole growth period of the bunch. More recent work by Caldwell⁴⁸⁵ using a dust containing 2% DDT showed distinct promise as a control measure. In some instances DDT was mixed with nicotine.

⁴⁸⁴ N. E. H. Caldwell, *The Control of Banana Rust Thrips*. Queensland Dept. Agr. and Stock, Div. Plant Ind. Research Bull. No. 16, 1938.

⁴⁸⁵ N. E. H. Caldwell, *Queensland Agr. J.*, 63, 83 (1946).

WORLD BANANA PRODUCTION AND TRADE

The banana industry suffered greatly under the impact of World War II. The continental European market practically closed in 1939, and the United Kingdom stopped importing bananas from Jamaica in 1940. The United States remained as the only large market, and when this country entered the war in December 1941, imports were drastically reduced.⁴⁸⁶

In prewar years, exports of bananas far exceeded the volume of any other fruit, and in fact they are even today the most important fruit in international commerce. Maness and Tucker⁴⁸⁷ have made rather a comprehensive study of banana production and trade; the data following are chiefly from their work.

Prior to World War II, the Western Hemisphere supplied an average of 83% of the tonnage of bananas entering international commerce. During the war years, the United States was the principal market for the fruit, importing 80% of all bananas entering international commerce. Other than the United States, main importers in the Western Hemisphere were Argentina, Chili, Canada, and Uruguay.

The United Kingdom was the largest importer of bananas in Europe prior to World War II; over 75% of her imports were bought from the British Empire. France was the second largest importer in Europe, most of the fruit coming from her possessions. Germany, the Netherlands, and Belgium were other large European importers.

⁴⁸⁶ A. J. Mullen, *Foreign Commerce Weekly*, 18, No. 13, 11 (1945).

⁴⁸⁷ H. Maness and R. G. Tucker, *World Banana Production and Trade*. U. S. Dept. Agr., Washington, D. C., April, 1946.

TABLE 49. INTERNATIONAL TRADE IN BANANAS (EXPRESSED AS 1000 BUNCHES) : AVERAGE 1934-38, ANNUAL 1940-47

Continent and country	1940	1941	1942	1943	1944	1945	1946	1947 ^a
EXPORTS FROM SPECIFIED EXPORTING COUNTRIES								
<i>North America</i>								
British Honduras	612	437	337	97	195	145	85	162
Costa Rica	4,217	3,155	4,835	2,267	1,884	2,479	4,920	6,103
Guatemala	7,370	8,306	6,955	5,019	4,919	8,547	9,758	14,884
Honduras	12,353 ^b	14,547	12,865	6,514	10,404	13,138	14,184	15,211
Mexico	12,230	5,907	3,977	3,548	3,981	3,502	5,039	5,645
Nicaragua	2,168	1,040	585	58	7	73	188	200
Republic of Panama	8,027	8,211	7,937	3,324	1,624	3,601 ^c	7,268 ^c	6,384
Panama, Canal Zone	1,541	1,746	1,676	555 ¹	5	4	d	d
Caribbean:								
Cuba	5,316	3,874	3,335	1,916	1,083	1,162	1,952	1,936
Dominica	57	38	49	12	4	4	4	4
Dominican Republic	88	630	835	620	377	971	1,221	930
Grenada	65	59	49	14	8	3	5	5
Guadeloupe	1,553	1,009	325	100	112	462	838	1,000
Haiti ^e	14,489	1,361	1,970	1,159	1,734	2,409	3,328	4,381
Jamaica	14,824	4,794	3,912	943	782	1,258	4,194	3,957
Martinique	1,192	463	103	0	5	0	144	596
St. Lucia	56	48	40	2	0	0	0	0
St. Vincent	22	21	14	0	0	0	0	0
Trinidad and Tobago	71	25	9	0	0	f	2	2
<i>Total North America</i>	72,251	55,671	49,808	26,149	27,124	37,758	53,330	61,400
<i>Europe</i>								
Spain	g	46	23	105	139	200	261	275
<i>Asia</i>								
Syria and Lebanon	4	63	4	f	f	11	15	15
Japan ^h	186	250	159	58	0	0	0	0
Formosa ⁱ	5,378	4,692	3,200	1,890	529	0	0	0
Formosa	704	668	576	231	0	0	173	412
Netherlands								
Java and Madura	88	106	86	0	0	0	0	0
Outer Provinces	38	52	0	0	0	0	0	0
<i>Total Asia</i>	6,398	5,831	4,025	2,179	529	11	188	427

Continent and country	1934-38 (av.)	1940	1941	1942	1943	1944	1945	1946	1947 ^a
<i>South America</i>									
Brazil	8,714	7,064	4,048	2,444	1,824	2,243	2,587	4,184	5,927
Colombia	7,122	5,652	3,400	2,96	1	532	1,516	1,820	2,000
Ecuador	2,100	2,024	1,467	968	677	595	763	1,500	2,979
Surinam	3	0	0	0	0	0	0	0	0
Venezuela	105	96	87	206	344	206	0	0	0
<i>Total South America</i>	<i>18,044</i>	<i>14,836</i>	<i>9,002</i>	<i>3,914</i>	<i>2,846</i>	<i>3,576</i>	<i>4,666</i>	<i>7,504</i>	<i>10,906</i>
<i>Africa</i>									
Algeria	5	2	0	0	0	0	0	0	0
Belgian Congo	58	40	35	35	40	40	51	78	88
Canary Islands	5,730	4,460	4,530	3,430	2,995	2,280	2,797	4,027	4,000
Egypt	17	1	0	0	0	5	6	10	10
Eritrea	885	691	0	0	0	0	0	0	0
French Cameroon	719	748	0	0	0	0	0	207	883
French West Africa:									
French Guinea	1,778	1,016	449	57	44	35	16	252	1,170
Ivory Coast	295	282	116	f	0	0	0	75	285
Gold Coast	33	54	5	f	f	1	f	f	f
Mozambique	443	436	793	979	1,199	951	1,086	1,100	1,100
Nigeria and Cameroom	1,982	2,627	0	2	2	1	1	386	400
Sao Tome and Principe	2 ^u	8	5	5	7	7	18	20	20
Union of South Africa	5	5	12	19	0	11	7	10	10
<i>Total Africa</i>	<i>11,959</i>	<i>10,370</i>	<i>5,945</i>	<i>4,527</i>	<i>4,287</i>	<i>3,331</i>	<i>3,982</i>	<i>6,163</i>	<i>7,966</i>
<i>Oceania</i>									
Fiji	286	181	95	183	154	74	140	230	250
Hawaii ³	98	105	90	0	0	0	0	0	0
Tonga Islands	31	42	78	81	63	48	52	60	60
Western Samoa	238	370	291	131	105	53	180	200	200
<i>Total Oceania</i>	<i>653</i>	<i>698</i>	<i>554</i>	<i>395</i>	<i>322</i>	<i>175</i>	<i>372</i>	<i>490</i>	<i>510</i>
<i>World total</i>	<i>109,312</i>	<i>87,452</i>	<i>69,357</i>	<i>37,269</i>	<i>28,612</i>	<i>34,874</i>	<i>46,989</i>	<i>67,938</i>	<i>81,484</i>
IMPORTS INTO SPECIFIED IMPORTING COUNTRIES*									
<i>North America</i>									
Canada	2,488	2,283	2,485	756	840	2,113	3,647	4,856	3,806
United States ¹	59,498	52,957	50,713	23,323	20,745	27,244	36,862	46,626	54,176
<i>Total North America</i>	<i>61,986</i>	<i>55,420</i>	<i>53,198</i>	<i>24,119</i>	<i>21,585</i>	<i>29,357</i>	<i>40,509</i>	<i>51,482</i>	<i>57,982</i>

(Table Continued)

TABLE 49 (contd.). INTERNATIONAL TRADE IN BANANAS (EXPRESSED AS 1000 BUNCHES): AVERAGE 1934-38, ANNUAL 1940-47.

Continent and country	1934-38 (av.)	1940	1941	1942	1943	1944	1945	1946	1947 ^a
IMPORTS INTO SPECIFIED IMPORTING COUNTRIES*									
<i>Europe</i>									
Belgium	986	114	0	1	0	0	4	4	4
Denmark	161	22	0	0	0	0	10	2	f
Eire	247	135	0	0	3	0	0	39	169
Finland	110	0	0	0	0	0	f	0	0
France	7,522	2,450	774	27	f	17	3	1,102	3,772
Germany	5,281	20	45	11	0	0	0	0	0
Italy	845	691	0	0	0	—	—	1	9
Netherlands	1,367	72	f	f	0	—	—	37	76
Norway	322	34	0	0	0	0	54	184	135
Spain	2,275 ^e	4,414	4,505	3,449	2,796	2,117	2,336	1,521	2,000
Sweden	439	62	0	0	0	1	83	956	580
Switzerland	291	145	24	104	163	100	164	324	334
United Kingdom	13,071	8,531	4	0	0	0	50	4,549	4,649
<i>Total Europe</i>	32,917	16,690	5,352	3,592	2,962	2,235	2,704	8,719	11,728
<i>Asia</i>									
Iraq	12	10	4	0	f	f	f	0	0
Japan ^m	5,378	4,692	3,200	1,890	996	529	0	0	0
Korea [†]	186	250	159	58	66	0	0	0	0
Palestine	0	51	13	41	67	92	110	170	200
<i>Total Asia</i>	5,576	5,003	3,376	1,989	1,129	621	110	170	200
<i>South America</i>									
Argentina	6,394	7,319	4,309	2,575	1,594	1,954	2,108	3,169	4,540
Chile	584	1,890	768	653	426	648	651	849	1,129
Uruguay	450	1,023	632	523	478	400	417	400	400
<i>Total South America</i>	7,428	9,232	5,709	3,751	2,498	3,002	3,176	4,418	6,069
<i>Africa</i>									
Algeria	233	158	8	f	0	0	0	0	0
South West Africa	14	4	4	6	7	10	6	10	10
Spanish Morocco	16	26	29	9	14	24	28	30	30
<i>Total Africa</i>	253	188	41	15	21	34	34	40	40

Continent and country	1934-38 (av.)	1940	1941	1942	1943	1944	1945	1946	1947 ^a
IMPORTS INTO SPECIFIED IMPORTING COUNTRIES ^b									
<i>Oceania</i>									
Australia	72	69	30	<i>f</i>	0	0	0	0	0
New Zealand	503	599	471	483	359	222	368	494	450
Total Oceania	577	668	501	483	359	222	368	494	450
Other countries ^c	411	55	0	0	0	0	0	173	412
World total	109,148	87,076	68,177	33,949	28,554	35,471	46,901	65,496	76,881

^a Preliminary. ^b Crop years Aug. 1-July 31, 1933-34 through 1936-37; Aug. 1-June 30, 1937-38; July 1-June 30, 1939; subsequent years are calendar. ^c Includes Panama Canal Zone. ^d Included in Panama Republic. ^e Year beginning Oct. 1. ^f Less than 500 bunches. ^g Less than 5 years. ^h Trade with Korea. ⁱ Trade with Japan. ^j Shipments to United States. ^k Reexports have been deducted. ^l Includes shipments from Hawaii. ^m Trade with Formosa. ⁿ Includes the following: 1934-38; Austria 43, Czechoslovakia 125, Hungary and Estonia each 2, Latvia and Lithuania each 5; Malta 18, Tangier 10, French Morocco 92, Tunisia 109, 1940; Malta 1, French Morocco 24, Tunisia 30, 1946; China 173, 1947; China 412.

Office of Foreign Agricultural Relations, Washington, D. C. Prepared or estimated on the basis of official statistics of foreign governments, reports of United States foreign service officers, results of office research and other information. All figures have been converted to count bunches of 50 lbs.

TABLE 50. IMPORTS INTO THE UNITED STATES BY COUNTRY OF ORIGIN OF DRIED, DESICCATED, OR EVAPORATED BANANAS^a

Country of origin	Pounds imported					
	1941	1942	1943	1944	1945	1946
Mexico	0	12,406	218,326	359,553	170,875	114,801
Guatemala	16,532	0	2,000	166,400	142,216	60,836
Honduras	300	99,085	420,897	373,121	63,500	10,345
Cuba	0	10	0	1,019	285,580	77,000
Costa Rica	0	0	400	0	0	0
Ecuador	0	13,200	2,000	0	0	0
Brazil	0	32,316	479,299	539,395	385,993	380,399
French West Indies	0	3,402	0	0	0	100
<i>Total</i>	<i>16,832</i>	<i>160,419</i>	<i>1,122,922</i>	<i>1,439,488</i>	<i>1,048,164</i>	<i>643,481</i>

^a Compiled from official sources by the Office of Foreign Agricultural Relations, U. S. Department of Agriculture, Washington, D. C.

TABLE 51. AVERAGE WEIGHT PER BUNCH (IN POUNDS) OF BANANAS IMPORTED INTO THE UNITED STATES IN 1943 AND 1944 AND FROM JANUARY TO JULY, 1945^a

Country of origin	1943	1944	1945
Mexico	34.6	33.1	36.1
Guatemala	59.9	62.3	61.8
Honduras	57.4	59.3	60.2
British Honduras	47.0	27.8	24.9
Nicaragua	—	29.8	33.2
Costa Rica	63.8	57.5	56.4
Panama	69.0	60.2	58.0
Canal Zone	70.0	46.6	59.0
Colombia	—	50.5	35.6
Ecuador	56.6	—	—
Bahamas	30.0	—	—
Cuba	27.4	22.5	22.2
Haiti	31.0	29.8	30.2
Dominican Republic	32.8	39.9	39.9
Jamaica	34.9	35.6	35.0
French West Indies	50.3	34.2	31.0
<i>Average</i>	<i>46.6</i>	<i>47.6</i>	<i>50.0</i>

^a Official Statistics, U. S. Department of Commerce, Washington, D. C.

In the first few years to come, the United States and other importing countries of the Americas are expected to take most of the available exports from the Western Hemisphere. If the relatively high level of consumer purchasing power is maintained in the United States, indications are that imports of bananas will exceed the record-high peacetime level, if the supply becomes available. Significant progress is being made in this direction by positive action against disease, opening up new lands, and improved methods of cultivation.

In 1947 the United States imported about 54.2 million count bunches of bananas and continued to be the world's largest importer. The United Kingdom was the second largest, importing 4.6 million; Argentina 4.5 million and France and Canada 3.8 million each. Of the bananas imported into the United States in 1947, Honduras supplied 13.7 million, Guatemala 11.7, Mexico 4.6, Costa Rica 5.6, Republic of Panama 4.8, Haiti 4.2, and Cuba, Colombia, and Ecuador about 2 million each; the Canal Zone and the Dominican Republic 1 million each.⁴⁸⁸

With the strained economy in Europe, it is not likely that imports there will be of significance for at least a year or two. Most of the fruit will then be imported from the Canary Islands and African Colonies.

⁴⁸⁸ Anon., *Foreign Agriculture Circ.* FDAP-5-48 (August 2, 1948). Office of Foreign Agricultural Relations, U. S. Dept. Agr., Washington, D. C.

AUTHOR INDEX

A

Adams, F. U., 8
 Alles, G. A., 103
 Angelo, J. J., 111
 d'Angremond, A., 5
 Ansbacher, S., 113, 114
 Arthur, J. M., 134
 Asby, S. F., 159
 Asenjo, C. F., 113

B

Badenoch, E., 146
 Bagaoisan, C. L., 101
 Bailey, A. A., 152
 Bailey, E. M., 39, 56, 69, 81, 82, 115,
 116, 117, 118
 Baillon, A. F., 19, 21, 22
 Baker, J., 59
 Baker, J. G., 1
 Bargen, J. A., 148
 Barnell, E., 60, 62, 65, 98, 99
 Barnell, H. R., 26, 42, 45, 60, 62, 65,
 67, 68, 69, 70, 71, 76, 78, 82, 83, 85,
 87, 90, 91, 92, 93, 94, 95, 98, 99, 101
 Bates, F. L., 87
 Bartók, H. A., 116, 118
 Beccari, N., 5
 Belval, M. H., 67, 68
 Benoble, S., 147
 Benzon, B., 105
 Bertrand, G., 105
 Bethea, H., 148
 Bethea, O. W., 148
 Biale, J. B., 50, 121
 Bigelow, W. D., 96
 Billings, H. E., 126
 Birch, T. W., 112
 Bitter, F. W., 10
 Blatherwick, N. R., 149
 Bogert, L. J., 143, 146, 147, 148, 149
 Bogin, M., 148
 Bolles, W. E., 13
 Botjes, J. O., 50
 Bottini, E., 54
 Bourdouil, C., 67, 69, 79

Brandes, E. W., 152
 Brenner, M. W., 51, 80, 82, 83
 Bridel, M., 79
 Brown, H. T., 99
 Brun, J., 156
 Brunner, H., 97
 Buignet, M. H., 79, 97
 Buogo, G., 112
 Burns, W., 130, 131
 Butler, E. J., 157
 Butler, L. F., 53

C

Caldwell, N. E. H., 164, 166
 Carteni, A., 128, 142
 Cefferi, R., 1
 Chace, E. M., 47, 82
 Chase, A. F., 149
 Chase, Mary Ellen, 9
 Chatin, M., 71
 Cheesman, E. E., 1, 4
 Christie, A. W., 126
 Chuard, E., 97
 Church, C. G., 47
 Cluggage, H. B., 112
 Collin, E., 85, 133
 Conrad, C. M., 89
 Cooper, L. F., 148
 Corenwinder, M. B., 79, 82, 95, 137
 Cornwall, E. E., 148
 Cousins, H. H., 128
 Cox, H. E., 86
 Cox, J. R., 82
 Craig, H., 146
 Craig, J. D., 147
 Crede, E., 99
 Cuille, J., 163
 Cullen, 98

D

Dale, N. I., 116, 118
 Dalldorf, G., 112
 DaSilveira, A. H., 131
 Davies, B. P., 112
 Day, H. F., 147

De Borinquen Segundo, O., 113
 De Caro, L., 112, 113, 114
 Dehusses, J., 143
 Delacroix, G., 159
 DeLapersonni, E. L., 137
 Denny, F. E., 47
 Dodds, K. S., 1
 Doherty, W. M., 82
 Dolger, H., 149
 Donath, W. F., 112
 Dunbar, P. B., 96

E

Eddy, W. H., 102, 103, 112, 114, 144, 145
 Eggebrecht, H., 139
 Ellis, R. H., 126
 Elmer, O. H., 51
 Elvehjem, C. A., 113, 114
 Engelfried, J. J., 103
 Esch, W., 35
 Evans, H. M., 113

F

Fabriani, G., 82, 128, 129, 142
 Falk, K. G., 115, 116, 117
 Fanconi, G., 147
 Fang, Y., 6, 129, 142
 Fawcett, W., 5, 24, 28, 138, 162
 Fegley, N. A., 82
 Finkelstein, B., 113
 Fisher, D. F., 50, 121
 Fonseca, C., 96
 Fourcroy, 22
 Freise, F. W., 139
 French, D., 87
 Fuento, C., 111

G

Gallot, S., 134
 Gane, R., 48, 51, 54, 55, 56, 72, 73, 75
 Garcia, E., 1
 García de la Noceda, H., 113
 Guadagnin, L., 1
 Gaumann, E., 155
 Geerlings, Prinsen, H. C., 35, 82
 Gerber, M. C., 71
 Girault, A. A., 164
 Givens, M. H., 112
 Gore, H. C., 69, 77, 81, 102

Grendel, F., 105
 Griebel, C., 35
 Grünwald, O., 141
 Grunninger, V., 112
 Guadagnin, L., 1

H

Haas, S. V., 146
 Haller, M. H., 90
 Hanausek, T. F., 85, 130, 133
 Hansford, C. G., 152
 Harris, L. J., 112
 Harris, P. L., 62, 80, 82, 83, 95, 96, 98, 110, 111, 112, 134, 144
 Harris, W. F., 163
 Harrison, D. C., 102
 Hartmann, B. G., 96
 Hartshorn, R., 53
 Harvey, R. B., 47, 48
 Hawkins, E. G. E., 86
 Heisler, 147
 Hellinger, E., 162
 Hemperty, C., 116, 118
 Hepburn, J. S., 82
 Herbert, D. A., 52
 Hibberd, R. P., 47, 49
 Higgins, H. L., 149
 Higgins, J. E., 152
 Hill, A. W., 4
 Hillig, F., 96
 Hindhede, M., 149
 Hoëtte, S., 161, 162
 Hofbauer, G., 74, 75
 Holmes, E., 19, 22
 Holzker, R., 142
 Hourwitz, A., 1
 Huber, P., 20, 21, 23
 Huelin, F. E., 50
 Hummel, F. C., 90, 91, 144, 147
 Hunscher, H. A., 144, 147
 Hutchinson, M., 7

J

Jacob, K. C., 128, 134
 Jacquot, R., 90, 145
 Jansen, B. C. P., 112
 Jessen, L. S., 6
 Johann, H., 152
 Johnson, M., 111
 Johnston, J. A., 147

Jojo, W. J., 96
 Jones, J. K. N., 86
 Joshi, P. G., 131
 Joslin, C. L., 148, 149

K

Kabat, E. A., 87
 Kahn, B. S., 148
 Kanagaratnam, N., 126
 Kantor, J. L., 148
 Kelley, J. N., 51
 Kellogg, M., 112
 Kerley, C. G., 146
 Kepner, C. D., Jr., 10
 Kervégant, D., 2, 20, 21, 156, 157, 159, 161, 162
 Kidd, F., 45, 46, 51, 56
 Kindt, L., 130
 Kleber, C., 107
 Koch, F. O., 28
 Kohman, E. F., 96
 Kulkarmi, L. B., 130

L

Langworthy, C. F., 72, 74, 116
 Lavastida, R. la Portilla y, 147
 Lavalloy, J., 131
 Leach, R., 154
 LeClerc, J. A., 132
 Lehrman, L., 87
 Leonard, E. R., 26, 30, 42, 45, 57, 58, 60, 67, 69, 72, 75, 76, 78, 101
 Leverton, R. M., 112
 Lewis, A. H., 19, 22
 Lewis, H. B., 112
 Locatelli, A., 112, 113, 114
 Lynch, L. J., 48, 52

M

McCance, R. A., 82, 144
 McCaughney, V., 1
 McGuire, G., 115, 116, 117
 McGuire, L. P., 4, 18, 59, 64, 122, 152, 158, 159, 160
 McKenzie, A. S., 136
 McKinley, D., 54
 MacLean, A. B., 146
 MacLennan, E. J., 161, 162
 McMaster, D. R., 90, 91

McNamara, J., 147
 Macy, I. C., 90, 144, 147
 Maness, H., 7, 11, 12, 155, 167
 Mangold, E., 90
 Manion, J. T., 77, 80, 81, 82, 83, 89, 94, 115, 116, 117
 Marcano, V., 128
 Marsh, T. D., 126
 Marth, P. C., 55
 Massee, G., 154
 Masuda, Mataemon, 115
 Maxwell, W., 26
 May, D. W., 22
 Mellenby, E., 102
 Meredith, C. H., 153
 Merny, G., 156
 Meunier, P., 105
 Mierau, F., 79, 82, 114, 116
 Mildbraed, J., 29
 Miller, E. V., 50, 121
 Miller, H., 103
 Milner, R. D., 72, 74, 116
 Mitchell, J. W., 55
 Montes, L., 10
 Moro, E., 147
 Morris, G. H., 99
 Morris, N., 146
 Moss, A. R., 105
 Müller, E. A., 133
 Mullen, A. J., 167
 Munsell, H. E., 112
 Munson, L. S., 82
 Muntz, A., 128, 137, 138
 Myers, V. C., 143

N

Naesland, C., 112
 Nagel, C., 137, 138
 Nelson, E. K., 96
 Nelson, J. M., 116, 118
 Nelson, R. C., 51
 Niederl, J. B., 51
 Niethammer, A., 96

O

Ogilvie, L., 157
 Olmsted, W. H., 90
 Olney, A. J., 73, 74
 Onslow, M. W., 97, 116, 118

P

- Pavarino, G. L., 62, 97, 99
 Pearce, J. A., 134
 Pease, M. C., 143
 Peratti, R., 137
 Perelli, S., 128, 142
 Phillips, R. C., 99
 Pigafetta, F., 7
 Piergrossi, A., 128, 142
 Piness, G., 103
 Plinius, 6
 Poland, G. L., 60, 62, 63, 64, 80, 82,
 83, 95, 96, 98, 110, 111, 112, 134,
 141, 144
 Pollack, H., 149
 Pope, W. T., 158
 Popenoe, P., 1, 4, 5, 7
 Popenoe, Wilson, 17, 18, 19, 42, 154
 Prinsen Geerlings. See *Geerlings*,
Prinsen, H. C.

R

- Ramirez, J. H., 139
 Ramsey, G. B., 53
 Ray, S. N., 112
 Raymond, W. D., 96
 Read, E. A., 82
 Regeimbal, L. O., 48
 Reich, R., 20, 81, 128
 Reichelt, G., 129
 Reichert, L., 162
 Reinking, O. A., 152
 Rettger, L. F., 148
 Reynolds, P. K., 6, 7, 8, 18, 120, 129,
 138, 142
 Riaboff, J., 149
 Ricciardi, L., 67, 81, 94, 95, 97
 Ridley, V. W., 50
 Ripa, R., 139
 Riviera, V., 137
 Rosa, J. T., 47
 Rose, A. R., 143, 149
 Rose, M. S., 112
 Rose, W. V., 5
 Roundier, H., 131
 Row, G. R., 98, 115
 Rundle, R. E., 87

S

- Sanchez, C. G., 1

- Sastri, B. N., 98, 115
 Savage, C. G., 134
 Schiaparelli, P., 112
 Schoffman, W. F., 149
 Scurti, F., 56, 57, 62, 97, 99
 Serrano, P., 113
 Shepard, M. L., 90, 144, 147
 Sherbakoff, C. D., 152
 Sherman, H. C., 113
 Simmonds, J. H., 156, 161, 162
 Simmonds, N. W., 1
 Skutch, A. F., 25
 Slocum, A. H., 29, 59, 64, 98, 121,
 124, 164
 Smith, A. J. M., 69, 74, 120
 Smith, E. F., 152
 Smith, J. H., 165
 Smith, R., 82
 Sohn, K. S., 82
 Sonders, H. J., 147
 de Sornay, P., 130
 Spencer, G. L., 4
 Spinden, H. J., 4, 6
 Spruyt, J. P., 118
 Stanley, H. M., 129
 Strong, F. M., 113
 Stone, W., 116, 118
 Stratton, F. C., 20, 69, 76, 77, 79, 80,
 89, 90, 94, 102, 105, 107, 115, 116
 Sullivan, R. C., 146
 Sydow, H., 157
 Sydow, P., 157

T

- Tallarico, G., 69, 114, 115, 116
 Taro, R. G., 159
 Tepley, L. J., 113
 Terrier, J., 143
 Teversham, T. F., 24
 Thornton, N. C., 46, 50, 53, 55, 56,
 95, 110, 111, 112
 Thursfield, H., 147
 Tolman, L. M., 82
 Tomkins, R. G., 121, 122, 158, 160
 Tryon, H., 164
 Tucker, R. G., 7, 11, 12, 155, 167
 Twigg, J. M., 149

U

- Ullan, E. A., 133

V

Vacha, 48
 Valdes, G. F. de Oviedo y, 6
 Van Horne, 112
 Vauquelin, 22
 Veitch, 163
 Venkataramani, K. S., 1
 Vilardebo, A., 133
 Vines, S. W., 114, 116
 Voegtlin, W. L., 148
 Von Becze, G., 120, 121, 122
 Von Loesecke, H. W., 20, 32, 35, 69,
 76, 77, 79, 80, 82, 89, 90, 95, 102,
 105, 107, 108, 126, 128, 132, 135,
 138, 139
 Von Noorden, C., 149
 Von Reuss, A., 148

W

Wada, C., 115
 Wallace, R. F., 82
 Ward, F. S., 131
 Wardlaw, C. W., 4, 17, 18, 19, 26, 42,
 45, 57, 58, 59, 62, 64, 69, 73, 75, 76,
 78, 101, 122, 152, 153, 154, 155, 156,
 157, 158, 159, 160
 Webster, P. J., 82
 Wehmer, C., 82, 95, 96
 Weinstein, L., 145, 148

Weiss, J. E., 145, 148
 Wessling, H. L., 132
 West, C., 45, 46, 51, 56
 White, P. R., 6, 27
 Widdowson, E. M., 82, 144
 Williams, R. D., 90
 Wilson, C. M., 8, 154, 155
 Wilson, R. M., 60, 63
 Winckel, M., 133, 137, 138, 141
 Winston, J. R., 50, 121
 Winton, A. L., 86
 Winton, K. B., 86
 Wolfe, H. S., 47, 49, 69
 Wolfson, A. M., 36
 Wollenweber, H. W., 152
 Wood, R. C., 19
 Woodman, R. M., 121, 122
 Wright, C. H., 128
 Wülfert, K., 57, 95

Y

Yoshimura, K., 82, 97
 Young, G. T., 86

Z

Zavanju, A., 49, 57
 Ziegler, M., 112
 Zimmerman, A., 154

SUBJECT INDEX

A

Acetaldehyde, 60, 99, 108
 effect on peel, 55
 Acetic acid, 96
 effect on peel, 55
 "Active tannin," 99, 100, 101
 Acetylene, ripening with, 53
 Acidity
 change during ripening, 74, 95-97
 in development of bunch, 68
 nature of, 95-97
Acidophilus bacteria in feces, 145
 Acids in pulp, 95-97
 Alcohol
 effect of, 55
 ethyl, 108
 preparation of, 137
 methyl, 108
 Allergens, removal of, 103-104
 Ammonia, effect on peel, 53, 54
 Amyl acetate, 108
 effect on peel, 54, 55
 on ripening fruit, 54
 Amyl esters of valeric acid, effect on
 ripening, 54
 Amylase, 114, 115, 116
 Amylose in banana starch, 87
 Anatomy of peel, 29-36
 Anthocyanins in peel, 108
 Anthracnose, 59, 159, 160
 "Apple bacove,"* 3
 "Apple," 3, 13
 "Apple fig," 3
 "Apple plantain," 3, 126
 Apples
 gas emanation from, 51
 physiological breakdown, 59
 Ascorbic acid, 110-112, 145
 destruction in dehydrating bananas,
 134
 effect of carbon dioxide, 46, 55, 56
 of chilling of fruit, 62
 of ethylene treatment, 53
 in other fruits and vegetables, 145
 retention in sliced bananas, 111
 use in freezing bananas, 142

Ascorbic acid oxidase, 116, 118
 Ash
 change during ripening, 105
 composition, 105, 106, 107
 effect of soil composition on, 20, 21
Aspergillus oryzae, 139
 Atlantic Fruit Company, 10
 Atlantic Fruit and Steamship Com
 pany, 10

B

"Baby doll," 3
 "Bacove fig," 3
 Banana bread. See *Bread*.
 Banana chips, 136
 Banana chocolate, 137
 Banana cocoa, 137
 Banana coffee, 136
 Banana flour, 127-134
 Banana freckle, 158
 Banana oil, 105
 "Banandinba," 3
 Banibs, 135, 136
 "Barbaro filos," 3
 "Baudin fig," 4
 Beetle borer, 163
 "Big bunch," 3
 "Big dwarf," 4
 Biotin, 114
 "Bird fig," 3
 "Black banana," 2
 Black finger tip disease, 159
 "Black musk," 2
 "Black plantain," 2
 Black spot. See *Banana freckle*.
 Black tip disease, 157
 Blood sickness, 154, 155
 symptoms, 155
 "Bluefields," 4, 126
 "Bluggoe," 3
 Bordeaux mixture, use in disease
 control, 155, 158
 Boric acid, 96
 Boston Fruit Company, 9
 Botryodiplodia fruit rot, 157, 158

* Names of banana varieties are given in quotation marks.

- Botryodiplodia theobromae*, 121, 157
 Boxing, 95, 124, 125, 140
 Bragmans Bluff Lumber Company, 11
 Bread
 banana, analysis, 133
 preparation from banana flour, 132-133
 Brewing, banana flour in, 138
 "Bumulan," 4, 126
 Bunch
 definition, 25
 morphology, 23-29
 number of fingers, 42
 number of hands, 42
 weight, 42, 172
 Bunchy-top disease, 156
 "Bungulan," 126
 "Burro," 3
 "Burro filos," 3
 "Butter bacove," 4
 Butyric acid, 96
 By-products. See *Products*.
- C**
- "Cabbage top." See *Bunchy-top disease*.
 Canning, 95, 140
 Carbohydrates
 change during ripening, 78-87
 utilization, 143, 146
 Carbon dioxide
 effect on ascorbic acid, 46, 55, 56
 on respiration, 56, 57
 on ripening, 45, 46, 55, 56
 on "ship ripens," 50
 evolution, 45, 71, 73
 in tissues, 57, 62, 75, 76
 pH changes by, 55
 Carbon monoxide, effect on ripening, 53
 Carboxylase, 118
 Cardiac diseases, use of bananas in, 149
 Carotene
 in peel, 108, 109
 in pulp, 111, 113, 145
Carpophitus hemipterus L., 133
 Catalase, 114, 116
 Catechol, 97, 118
 Cattle feed, 141
Carthartus quadricollis Guer., 133
 "Cavendish," 60, 126
 Celery, blanching with ethylene, 47
 Celiac disease, use of bananas in, 146, 147
 Celluloses, changes during ripening, 90-93, 144, 145
Cercospora musae Zimm., 154
 "Chamaluco," 3
 Chemical changes during ripening, 67-118
 Chiclike gum in peel, 35
 analysis, 36
 Chilling
 color changes, 60, 63
 effect of, 58, 59-66, 71, 88
 Chips, 136
 Chlorenchyma, 30, 33, 65
 Chlorophenolmercuric hydroxide for control of Panama disease, 153
 Chlorophylls in peel, 108-109
 Chocolate, 137
 Cigar end disease, 156
 "Cineto a la boca," 3
 Citric acid, 96
 Citrus fruits, evolution of ethylene by, 50
 "Claret," 3
 Climate for growing, 12
 Climacteric, 72
 Coating, 59
 Cocoa, 137
 Coefficient of ripeness, 69
 Coffee, 136
 "Coffee fig," 3
 "Colibrifig," 3
 Colitis, value of bananas in treatment of, 148, 149
 "Collie," 3
 Color changes in peel during ripening, 40-41
 "Common plantain," 2. See also *Plantain*.
 Composition, 117
 Confection, banana, 135
 "Congo," 126
 Constipation, use of bananas in, 148
 Copper, 105
 "Creole," 2
 Crude fiber, 90, 144, 145

Crystallized banana, 135
 "Cuatro filos," 3
 "Cuban," 3
 Cultivation, 17-20
 Cutin, 31
 Cuyamel Fruit Company, 10

D

2,4-D, effect on ripening, 55
Dactylosterum hydrophiloides as a
 control for banana weevil borer,
 163
Dacus tryoni Frogst., 164
 "Date," 3
 DDT as a control for rust thrips, 166
 Dehydration, 127-134
 Dehydroascorbic acid, 111
 "Dessert fig," 3
 Dextrinase, 118
 Dextrose. See *Glucose*.
 Diabetes, use of bananas in, 149
 Diarrhea, use of bananas in, 147, 148
 Diastase. See *Amylase*.
 Diet of children, bananas in, 147
 DiGiorgio Importing and Steamship
 Company, 10
Diplodia musae, 157
 Diseases, 151-163
 Diseases (human), use of bananas in,
 143-149
 Distance between plants, 18
 Distribution, 124
 "Dwarf plantain," 2. See also *Plan-*
tain.
 Dysentery, bacillary, use of bananas
 in, 148

E

Elder, Dempster and Company, 11
 Elders and Fyffes, 11
 Enzymes, 114-118
 Epidermis of peel, 29-31
 Ethyl acetate, effect of, 55
 Ethyl alcohol, 108
 effect of, 55
 preparation of, 137
 Ethylene
 acceleration of ripening, 47-53
 of starch hydrolysis, 47, 48, 49,
 52

Ethylene (*contd.*)
 effect on ascorbic acid, 53
 on respiration, 48, 49
 evolution by bananas, 45, 51, 52
 by citrus, 50
 by molds, 121
 hydrolysis of starch by, 47, 48, 49
 mechanism of action of, 51, 52
 use to stimulate ripening, 47-53
 Ethyl mercury iodide for control of
 Panama disease, 153
 Exports, 168-171
 exporting countries, 11-15
 "Eyeless," 2

F

Fatty acid content of banana starch,
 87
 Fatty material, change during ripen-
 ing, 105
 Fertilization of soil, 19
 Fibrovascular bundles of peel, 29,
 33-34, 66
 "Fig," 3, 113
 Figs, banana, 134, 135
 Finger
 definition, 25
 number per bunch, 42
 "Fiji," 4
 "Fique ti-malice," 3
 Flavones in peel, 108
 Flavoring constituents, 107, 108
 Flooding of lands to control Panama
 disease, 153
 Florida Banana Growers' Associa-
 tion, 12
 Flour, 127-134
 analyses, 128
 fluorescence, 134
 imports, 172
 in brewing, 138
 odor, 130
 Flowering stalk, development, 26-28
 Flowers
 alleged medicinal effect, 143
 types, 26, 27, 28
 Fluorescence of bana flour, 134
 Folic acid, 114
 "Fourteen foot," 2
 Franc, Carl B., 8

Freckle, 158
 Freezing, 141-142
 Freezing point of sap, 64
 Fructose, 82, 83, 84
 Fructose diphosphate, 118
 Fruit fly, 164
 Fruit spot disease, 162, 163
Fusarium oxysporum cubense, 152, 153
Fusarium semitectum, 122
 Fyffe, Hudson & Co., 11

G

DL-Galactose, 83
 Gas injury, 58
 Gas storage, 55-59
 Gases, internal, 57, 60, 62, 75, 76, 101
 Gels, formation by banana extracts, 117
 Genetics, 5
 Geographical distribution, 124
 producing countries, 11-15, 167-173
 "Giant," 2
 "Giant fig," 4
 "Giant Guinea," 4
 "Giant plantain," 2. See also *Plantain*.
 "Giant red," 3
 "Giuba," 4
Gloeosporium musarum, 121, 158, 159, 160
 Glucose, 82, 83, 84
 Glycosuccinic acid, 97
 "Gold," 3
 "Gold fig," 3
 "Go-sai-heong," 3
 Gout, use in, 149
 Grades, 40-41, 42
 "Gros Michel," 4, 5, 7, 17, 57, 59, 60, 64, 76, 80, 81, 89, 95, 96, 106, 107, 117, 126, 152, 153, 154, 158
 "Guaran," 4
 Guard cells, 30
 Gum in latex of peel, 35, 36

H

Hall, J. and E., 11
 Hand
 definition, 25

Hand (*contd.*)
 number of fingers, 25
 "Hartton plantain," 2
 Harvesting, 28, 39-43
 Heat evolved during ripening, 74, 75, 120
Helminthosporium torulosum (Syd.), 157
 Hemicelluloses, 90, 91, 92, 93, 145
 role of, 91, 93, 145
 Hexose monophosphate, 118
 History and growth of trade, 1-15
 Holding temperatures, 46
 "Horn," 2
 "Horn plantain," 2. See also *Plantain*.
 "Horse plantain," 2, 126. See also *Plantain*.
 Humidity, relative, during ripening, 44-46
 Hybrids, 5
 Hydrogen peroxide, effect on peel, 54
 Hydrogen sulfide, effect on peel, 54
 Hypertension, use of bananas in, 149

I

"Ianga," 2
 Imperial Direct Line, 11
 Importing countries, 8, 172
 "Indio," 3
 Inflorescence, development, 26-28
 Inositol, 101, 114. See also *Vitamins*.
 Insects infesting banana flour, 133
 Insect pests, 163-166
 Internal gases, 57, 60, 62, 75, 76, 101
 Intestinal flora, change by bananas, 145
 Invertase, 79, 80, 81, 114, 115, 116, 117
 Invert sugar, 82
 Iodine, effect on peel, 54
 Iron, availability, 144
 Irrigation of banana lands, 19

J

Jam, preparation, 141
 Jelly, analysis, 142
 "Johnson," 4
 Jones, Sir Alfred, 11

K

- "Kakambou," 3
- Keith, Minor C., 9
- Kidney worms in pigs, use of stalks
for, 125, 126
- "Klui-nak," 3
- "Klui-nam-wa," 3

L

- "Lacatan," 4, 76, 80, 81, 89, 95, 106,
107, 117, 126, 152
- Lactase, 118
- "Lady finger," 3, 76, 80, 81, 89, 95,
106, 107, 117, 126
- Laemophloeus ferrugineus* Steph.,
133
- "Largo filos," 3
- Lasiodiplodia* fruit rot, 160, 161
- Lasiodiplodia theobromae* (Pat.),
160
- Laxative effect, 144, 145, 148
- Latex
 - analysis, 35, 36
 - separation of gum from, 36
 - system
 - of peel, 31, 34, 65, 66
 - of pulp, 38, 98
- Leaf growth, 26
- Leaves, alleged medicinal effects, 143
composition, 20, 21
- Lemons, ethylene treatment, 47
- Lignin, 90, 91, 144, 145
- Lipase, 116, 117
- "Little dwarf," 4
- Loading, 119. See also *Transporta-
tion*.

M

- "Maça," 3
- "Macho plantain," 2. See also
Plantain.
- Macrophoma musae* Berl. and Vogl.,
158
- "Mafafa," 3
- "Makabon," 3
- "Makanguia," 4
- Malic acid, 95, 96
- Malnutrition, use of bananas in, 147
See also *Nutritive value*.

- "Malongo," 3
- Maltose, 82, 83
- DL-Mannoheptose, 83
- D-Mannose, 83
- "Manzana," 3
- Marasmic infants, use of bananas in
diet, 147
- Marketing, 127, 128
- Marmalade, analysis, 142
- "Martinique," 8
- "Masak Hijau," 4
- "Massao," 3
- Maturing. See *Ripening*.
- Melizitose, 83
- Methyl alcohol, 108
- Mexican American Fruit and Steam-
ship Company, 11
- Mineral constituents of fruit and
tree, 20
- Moisture, change during ripening, 68,
69, 76-78
- "Moko," 3
- Molds
 - evolution of ethylene by, 121
 - growth on bananas, 120
- Morphology
 - of bunch, 23-29
 - of fruit, 29-38
 - of chilled fruit, 64-66
 - of peel, 29-36
 - of pulp, 36-38
- Mulch from banana stalks, 125
- Musa arnata chittagong*, 5
- M. basjoo*, 5
- M. cavendishii*, 13
- M. corniculata* Rumph., 2
- M. nana*, 4
- M. paradisica* L., 2
- M. sapientum* L., 3, 7, 96, 113
- "Musk," 2
- Mycosphaerella musicola*, 154

N

- Nephritis, acute, use of bananas in,
149
- Niacin, 113
- Nigrospora musae*, nov. sp., 161
- N. sphaerica*, 161
- Nitrogen, effect of, 57

- Nitrophenolmercuric hydroxide for
control of Panama disease, 153
Nutrients, effect on growth of plant,
21
Nutritive value, 143-149

O

- Odorous constituents, 107, 108
Oil, 105
Olefins, effect on ripening, 53
Ontogenetic development of the
bunch, 23-29
Oranges, emanation of gases from,
50
"Ordinary big dwarf," 4
Origin, 4-7
Oryzaephilus surinamensis L., 133
Osmotic pressure in pulp and peel, 77,
78
Oxalic acid, 96
Oxidases, 50, 116, 118
Oxygen
effect on respiration, 56, 57
on ripening, 46, 56, 57, 58
internal concentration, 57, 60, 62,
75, 76, 101
uptake, 55
Oxygenase, 118
Ozone, effect on peel and ripening,
54, 55

P

- Panama disease, 151-153
control, 153
symptoms, 152, 153
Panchamruthan, 135
Pantothenic acid, 114
Parenchyma of peel, 29, 31-33
analysis, 32
"Patriota Guinea," 4
Pectin
analysis, 139
changes during ripening, 89, 90
preparation, 139, 140
Peel
amylase in, 115
anatomy, 29-36
anthocyanins in, 108
carotene in, 108, 109
cattle feed from, 141

Peel (*contd.*)

- change in color during ripening,
40-41
chlorophylls in, 108, 109
color changes due to chilling, 60,
63
effect of ripening agents on, 53-55
epidermis, 29-31
fibrovascular bundles, 29, 33-34, 66
flavones in, 108
gum in, 35, 36
latex system, 31, 34, 65, 66
loss in weight during ripening, 69-
70
mineral constituents, 20
osmotic pressure, 77
parenchyma, 29, 31-33
pigments, 108-109
sap, freezing point, 64
tannins in, 79, 97-100
xanthophylls in, 108, 109
Penicillium digitatum, 121
evolution of ethylene by, 121
Pentalonia nigronervosa, 156
Peptic ulcers, use of bananas in, 149
"Pernambouc," 2
Peroxidase, 116, 118
Pestalozzia in pitting disease, 158
Pests of bananas, 163-166
pH of bananas, 55, 74, 95
Phosphatase, 118
Phosphorus, availability, 144
Phytic acid, 101
Phytin, 101
Phytosterol in banana starch, 87
"Piche," 3
Pigments of peel, 108-109
"Pikien missifinger," 3
"Pineapple fig," 3
Piricularia grisea (Cke.) Sacc., 158
"Pisang embu," 4
"Pisang rajah udang," 3
"Pisang tandok," 2
Pitting disease, 158, 159
Plaesus javanus as a control for the
weevil borer, 163
Plantain, 1, 76, 80, 81, 89, 95, 96,
106, 107, 113
Planting and cultivation of the tree,
17-20
"Plumed," 2

"Post," 3
 Powder, banana, 128, 129, 131, 132
 analyses, 128
 fluorescence, 134
 Preston, Andrew, 9
 Producing countries, 11-15, 167-173
 Products, 127-142
 Propagation, 17, 23, 24
 Protease, 114, 115, 116
 Protein
 changes during ripening, 102-104
 digestibility, 144
 extraction, 102-103
 nature, 102, 103
 Protopectin, changes during ripening, 89, 90
 Protoplasm, 33, 65
 "Prune fig," 3
 Pseudostem, 20, 23
Pseudomonas celebensis, nov. sp., 155
 Pulp, morphology, 36-38
 osmotic pressure, 77
 Pulp-to-peel ratio, 68-71
 Pyridoxine, 114

R

Raffinase, 118
 Raffinose, 83, 118
 "Raimbaud fig," 4
 Rasayanam, 135
 Ratio, pulp-to-peel, 68-71
 "Red," 3, 76, 80, 81, 89, 95, 117
 "Red creole fig," 3
 "Red fig," 3
 "Red Guinea," 3
 Refrigerated gas storage, 57, 58
 Relative humidity during ripening, 44-46
 Respiration, 71-76
 effect of carbon dioxide, 56, 57
 of ethylene, 48, 49
 of oxygen, 56, 57
 of temperature, 73
 Respiratory quotient, 71, 72
 Rhamnose, 83
 Riboflavin, 113, 145
 Ripening 43-55
 change in acidity, 95-97
 in ash, 105

Ripening (*contd.*)
 in carbohydrate, 78-87
 in celluloses, 90-93
 in fatty material, 105
 in moisture, 68, 69, 76-78
 in pectin, 89, 90
 in pigments of peel, 108-109
 in protein, 102-104
 in protopectin, 89, 90
 in rooms, 44
 in tannins, 79, 97-100
 in vitamins, 110-114
 chemical changes, 67-118
 temperatures, 44-46
 use of acetylene in, 53
 of ethylene in, 47-53
 of 2,4-D in, 55
 "Roatan," 4
 "Rose fig," 4
 Rot(s)
 loss of fruit due to, 120, 121
 means of reducing, 122, 123
 stem end, 121
 Rust, 165
 Rust thrips, 164-165
 control, 166

S

"Saint Pierre," 2
 Sap, peel, freezing point, 64
 Scab, 163, 164
Scirtothrips signipennis Bogn., 164, 165
 Sclerotina rot, 151
Sclerotina sclerotiorum, 162
 "Seven weeks," 3
 Shipping. See *Transportation*.
 Ship ripe, effect of carbon dioxide, 50
 Sieve tubes, 33, 34
 Sigatoka disease, 151, 154-155
 control, 155
 symptoms, 154-155
Sitophilus oryzae L., 133
 Sitosterol in fat of bananas, 105
 Sociological aspects of the industry, 10
 Soil
 composition, effect on ash composition of fruit, 20, 21
 fertilization, 19

- Sorbose, 83
 "Sour," 3
 Specific heat, 75
Sphenophorus sordidus, 163
 "Sprung" fruit, 30, 76, 99, 101
 Squirter disease, 151, 161, 162
Stachylidium theobromae Turc., 156
 Stalk
 as feed for pigs, 125, 126
 as mulch, 125
 ash, composition, 126
 composition, 20, 21, 125, 126
 flowering, 26
 Standard Fruit and Steamship Company, 11
 Starch, 85, 86, 87
 acceleration of hydrolysis by ethylene, 47, 48, 49, 52
 by 2,4-D, 55
 amylose in, 87
 68
 change during ripening, 81, 84, 87
 digestibility, 143
 during development of bunch, 67, 68
 fatty acids in, 87
 hydrolysis by ethylene, 47, 48, 49, 52
 in cells of chilled fruit, 88
 optical rotation, 87
 phytosterol in, 87
 Stem, definition, 25
 Stem end rot, 121
 Stomata, 30, 55, 59, 64, 65
 Storage and ripening methods, 39-66
 Structure and development, 17-38
 Sugar
 in chilled fruit, 60, 62, 88
 development of bunch, 67, 68
 in peel, 78
 in pulp, 73, 80, 81, 82, 83, 84
 "Sugar," 3
 "Sugar fig," 3
 Sulfur, effect on peel, 54
 Sulfur dioxide, effect on peel, 54
 Sulfuring of banana slices, 131
- T**
- Tannins, 60, 99, 100, 101, 115
 change during ripening, 79, 97-100
 in chilled fruit, 62
 Tannins (*contd.*)
 in juice of the tree, 23
 nature, 97, 98, 103, 144
 Tartaric acid, 96
 Temperature,
 effect on respiration, 72, 73
 holding, 46
 of ripening, 44-46
 Therapeutic qualities, 148, 149
 Thiamin, 113, 145
Thielaviopsis fruit rot, 160
T. paradoxa, 121, 122, 160
 Thrips, 164-165
 Titratable acidity, change during ripening, 74, 95-97
 Tocopherols, 114
 Tomatoes, ripening with ethylene, 47
 Tracheae, 34
 Trade, history, and growth, 1-15
 Transportation, 119-126
 railway, 122, 123
 rots during, 120, 121
 Tree,
 juice, 22, 23
 mature, composition, 21, 23
 mineral constituents, 21, 22
 percentage composition, 21
 planting and cultivation, 17-20
 "True," 2
 "Titiaro," 3
 Typhoid fever, use of bananas in, 149
- U**
- Ultraviolet light
 effect on peel, 54
 on ripening, 54
 fluorescence of banana flour by, 134
 Underbrushing, 18
 United Fruit Company, 9, 10, 11
 Uremia, use of bananas in, 149
 Utricle, protoplasmic, 33
- V**
- Varieties, 1-4. See also under individual varieties.
 Vaseline, effect on peel, 54
 Vegetable tannates, 98
 "Vinegar," 3
 Vinegar, 138, 139
 "Violet bacove," 3

"Violet," 3
 "Violet colored," 3
 "Violet fig," 3
 "Violet Guinea," 3
 Vitamin A. See *Carotene*.
 Vitamin B. See *Niacin*.
 Vitamin B₁. See *Thiamin*.
 Vitamin B₂. See *Riboflavin*.
 Vitamin B₆. See *Pyridoxine*.
 Vitamin B₉. See *Folic acid*.
 Vitamin C. See *Ascorbic acid*.
 Vitamin E. See *Tocopherols*.
 Vitamin H. See *Biotin*.
 Vitamins
 change during ripening, 110-114
 effect of ethylene, 53
 in different fruits and vegetables,
 145
 Volatile constituents, 107, 108

W

Water, transfer from peel to pulp, 77,
 78

Water content. See *Moisture*.
 Weevil borer, 163
 Weight of bunch, 42, 172
 "White musk," 2
 "White plantain," 2. See also *Plan-
 tain*.
 "Whitehall plantain," 3. See also
 Plantain.
 Wilt, 152
 Wine, preparation from bananas, 138

X

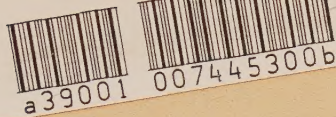
Xanthophylls in peel, 108, 109
 X-gas, 50

Y

Yeast, bananas in preparation of, 138
 "Yellow," 2

Z

Zermurray, Sam, 10



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